SAGUARO NATIONAL PARK,

ARIZONA

WATER RESOURCES SCOPING REPORT

David N. Mott

Technical Report NPS/NRWRD/NRTR-97/95

WATER RESOURCES DIVISION

National Park Service - Department of the Interior
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United States Department of the Interior
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CONTENTS

LIST OF FIGURES

EXECUTIVE SUMMARY

Water is a critical resource at Saguaro National Park, essential to the area's biologic communities in the midst of a harsh, desert environment. The park consists of two districts, between which lies the growing metropolitan area of Tucson, Arizona. Past land use activities, ongoing ground water withdrawals, and continued growth in the Tucson area have created major changes in hydrologic processes and riparian landscapes within and adjacent to the park.

The purposes of this Water Resource Scoping Report are to: 1) summarize existing information about the water resources of Saguaro National Park; 2) determine and briefly evaluate water resource issues in the park; 3) make recommendations regarding how these issues should be addressed; and, 4) develop proposals and technical assistance requests to take action where appropriate.

Rainfall in the Tucson Basin, where Saguaro is located, averages 11 inches per year. There are two rainy seasons -- July through September and December through March. Ephemeral stream flow in the Tucson Basin is triggered by intense summer thunderstorms and occasionally by prolonged periods of winter precipitation. The park's higher elevations have cooler temperatures and rainfall averaging up to 34 inches per year.

Saguaro National Park's land base consists of major portions of the Rincon Mountains to the east and Tucson Mountains to the west of Tucson. These steep, rugged mountain ranges were uplifted and eroded while the Tucson Basin filled with massive amounts of erosional deposits. Alluvial fan deposits occur within park boundaries along the basin's perimeter. Soils are typically shallow, coarsely textured, and well-drained and lend themselves to rapid recharge, particularly in stream channels.

Most of the park drains into the Santa Cruz River, which flows from south to north through Tucson. The east flank of the Rincon Mountain District (RMD) drains into the San Pedro River, while the west flank of the Tucson Mountain District (TMD) drains into Brawley Wash and the Avra Valley. Watersheds within the two districts are typically small, containing first, second, and third order streams. Surface drainage generally flows from the park to adjoining lands, except for a small section in the Rincon Valley where three creeks flow from park land, across private land, then enter the NPS expansion area as Rincon Creek.

Although streams within the park are perennially interrupted, intermittent or ephemeral, ground water often occurs near the surface along these water courses, and provides for many areas of high quality riparian habitat. Moisture that falls within the park contributes significantly to recharge of adjoining aquifers via stream channel and mountain front transport and infiltration mechanisms. Tucson relies heavily on ground water, and currently pumps more than twice the annual recharge. The City of Tucson Water Department (Tucson Water) is required by state law to balance withdrawal and recharge by the year 2025, but at present ground water mining continues in both the Tucson Basin and Avra Valley. The majority of the Tucson Basin has experienced ground water declines, and water levels in Avra Valley have also declined. The drawdowns that result from this pumping may have an effect on some of the riparian habitats near park boundaries.

Historic accounts and research indicate that the hydrology of the Tucson area has changed significantly in the past 100 years. In the mid-1850s, the entire valley was a forest of mesquite trees, with cottonwoods, willows and walnuts along the major streams. Much of the area was marshy, and malaria was a major problem for the original Fort Lowell along the Santa Cruz River. The introduction of cattle, the cutting of trees for fuel and building materials, and possibly a drought in the late 1800s led to changes in the hydrology such as down cutting of stream channels and dewatering of streambeds. The beavers, fishes and marshes disappeared; deep arroyos only occasionally filled with water replaced the marshes. Some of these changes still occur, and must be considered when evaluating the significance of water resources and riparian habitats within Saguaro National Park.

Elevations from 2,165 feet in TMD to 8,664 feet in RMD create a diversity of vegetation types; from desert scrub to grasslands and woodlands, to pine and mixed conifer forests. Each life zone has distinctive riparian plant communities dependent upon ground water near the surface. These riparian ecosystems are some of the most important and endangered habitats in the desert southwest. They are critical for plants dependent upon shallow water tables and numerous species of birds, mammals, herptofauna and insects. The balance between ground water levels, dependent vegetation, and associated wildlife can be particularly sensitive to alteration. Even small water table declines or increased fluctuation can negatively impact riparian habitats, which are not adapted to repeated or prolonged stress. Excessive extraction of near surface ground water from areas adjacent to Saguaro National Park is the most serious potential threat to the water resources of the park. Near boundary drawdown could result in water table declines that extend into park lands and impact vegetative communities dependent on near-surface ground water.

The following actions are recommended in response to this issue:

•Conduct a hydrologic and biologic inventory of water sources and riparian areas;

•Develop a conceptual model to determine the hydrologic connectivity between potential development areas and riparian environments;

•Carry out background investigations to locate and interpret water level data to quantify present ground water conditions and seasonal fluctuations in water tables;

•Map relationships between water levels, saturated sediment thicknesses, and ground water dependent vegetation;

•Determine if a ground water monitoring scheme should be developed based on the background investigations;

•Request that the Water Resource Division provide water rights guidance to NPS managers involved in purchasing lands or easements within the expansion areas;

•Review water level records for the park's water wells and determine if water table declines have the potential to reduce the production of these wells; and,

•Determine if aquifer compaction and land subsidence is a potential threat to park infrastructure.

The following list includes other water resource issues at Saguaro National Park and a summary of recommended responses.

ISSUE	**RECOMMENDATION**
•Water rights adjudication	Conduct a surface/ground water rights/resources inventory to determine the dependence of the water-related resource attributes on surface/ground water. This would provide key information required for adjudication.
•Lack of basic hydrologic data	Conduct an inventory of water sources and riparian areas.
•Mining and mineral development	Allow tailings piles to revegetate through natural processes. Use lime treatments to facilitate plant recruitment in acidic areas.

•Erosion of roads and trails	Cross streams and washes at the elevation of the stream bed, construct roads and trails with a positive slope, wing ditch and drain to low slope areas, keep grades to a minimum.
•Ground water contamination	Continue monitoring public water supply wells in accordance with state and federal regulations.
•Check dams, windmills and watering ponds	Allow check dams to deteriorate. Maintain only if culturally or biologically significant.
•Exotics and rare or endangered species	Conduct biological inventory of water sources and riparian areas.
•Air quality/atmospheric deposition	Monitor atmospheric deposition as part of the National Atmospheric Deposition Program.
•Contamination of the Manning Camp water supply	Relocate pit toilets down-gradient from the water source and continue chlorination program.

Specific recommendations designed to address the most urgent of these issues are included as Appendices A and B. The Water Resources Division of the National Park Service has committed funding and is now working with the park and local water resource specialists to address some aspects of the ground water issue. Other issues can be included in the park's Resources Management Plan. The need to develop a more comprehensive water resources management plan for Saguaro is not anticipated at this time.

INTRODUCTION

Water is a critical resource at Saguaro National Park, essential to the area's biologic communities in the midst of a harsh, desert environment. Springs, seeps, perennial stream reaches, and riparian areas sustain unique habitats important in maintaining the desert ecosystems the park was established to protect. Past land use activities, ongoing ground water withdrawals, and continued growth in the Tucson area have created major changes in hydrologic processes and riparian landscapes within and adjacent to the park. Basic data describing and quantifying the park's water resources have never been collected; therefore, changes in plant and animal communities can not be correlated with alterations of fundamental hydrologic factors responsible for the existence of these ground and surface water influenced areas.

The purposes of this Water Resource Scoping Report are to: 1) summarize existing information about the water resources of this park; 2) determine and briefly evaluate water resource issues in the park; 3) make recommendations regarding how these issues should be addressed; and 4) develop proposals and technical assistance requests to take action where appropriate.

Water resources related issues discussed in this report include:

- water table declines and associated loss of phreatophytic vegetation, decreased capacity of water supply wells, aquifer compaction and land subsidence, and fracture dewatering of springs and seeps
- water rights adjudication
- lack of basic hydrologic data
- mining and mineral development
- erosion of roads and trails
- ground water contamination
- check dams, windmills, and watering ponds
- exotics and rare and endangered species
- air quality/atmospheric deposition
- contamination of Manning Camp water supply

Because of the complex nature of these issues, especially the hydrologic/biologic interactions associated with water table declines, further water resource investigations are needed to protect park resources. Specific projects and investigations designed to address many of these issues are described in Appendix A and B. Recommendations were developed for each of the identified issues; therefore, the need to develop a more comprehensive water resources management plan is not anticipated at this time.

EXISTING RESOURCE CONDITION

Water is often a significant resource in units of the National Park Service (NPS), either through support of natural systems or providing for visitor use. The NPS seeks to perpetuate surface and ground waters as integral ecosystem components by carefully managing the consumptive use of water and striving to maintain the quality and health of aquatic ecosystems in accordance with all applicable laws and regulations. Water resource inventory and monitoring activities are, therefore, essential activities of park resource management.

This water resources scoping report summarizes existing water resource information and identifies and discusses a number of water-related issues and management concerns pertinent to Saguaro National Park. It provides information required by the Water Resources Division of the NPS to determine if a water resources management plan is needed for this park. Additionally, the summary of water related issues can assist with park resource management and be incorporated into the park's resource management plan.

LOCATION AND LEGISLATION

Saguaro National Park (SAGU) is located in southeastern Arizona (Figure 1) near the northern limits of the Sonoran Desert. The park is comprised of two separate districts, Rincon Mountain District (RMD) to the east of Tucson, and Tucson Mountain District (TMD) to the west. RMD was originally established as Saguaro National Monument in 1933, to preserve and protect "the exceptional growth thereon of various species of cacti including the majestic saguaro cactus," along with the scientific interest of the area [Presidential Proclamation (Proc.) 2032]. In 1961, lands within the Tucson Mountains were added to the monument to protect this area from mining development (Proc. 3439). Boundary expansions occurred in 1976, 1991, and 1994, bringing the total acreage to 24,034 acres in TMD, and 67,293 acres in RMD, for a total of 91,327 acres. The 1994 legislation [Public Law (P.L.) 103-364], also upgraded Saguaro National Monument to a National Park. Wilderness designation covering 13,470 acres (56%) and 57,930 acres (86%) in TMD and RMD, respectively, occurred in 1976 (P.L. 94-567).

Both districts lie within Pima County, adjacent to the east and west of Tucson. Tucson's population has grown from 265,000 in 1965, to 700,000 in 1995, and associated development adjoins both districts. RMD is bordered on the south, east, and north by the Coronado National Forest, covering about three fifths of this district's boundary, while most of TMD's southern boundary is adjacent to Pima County's Tucson Mountain Park.

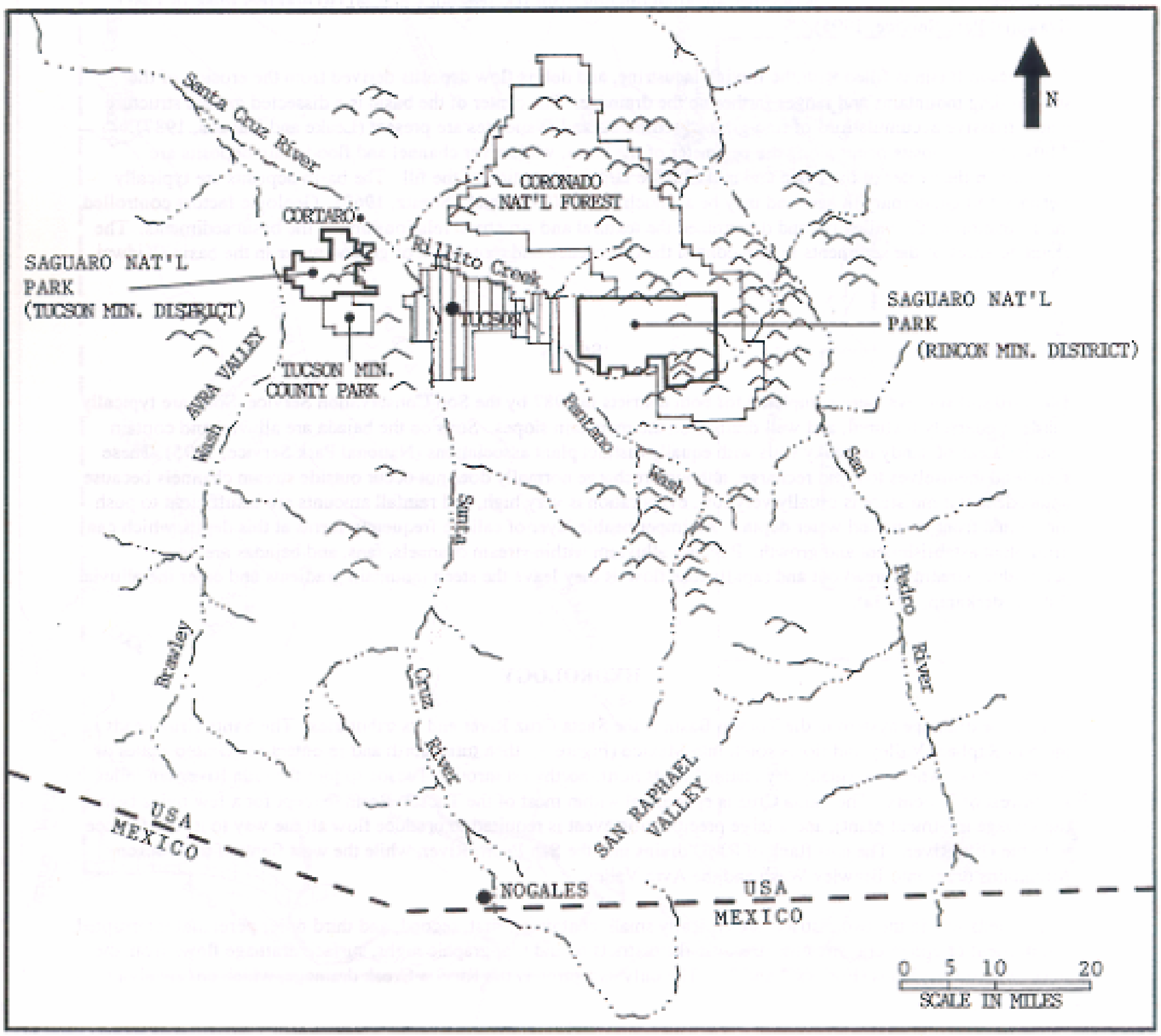
CLIMATE

In the Tucson vicinity, annual rainfall averages 11 inches, while average potential evaporation is 90 inches, resulting in an arid environment. Temperatures in the lower elevations of the park exceed 100 degrees F about 70 days (20%) per year, and freezing temperatures occur about six nights per year. Temperatures average 20 to 30 degrees F cooler at higher elevations of the Rincon Mountains, and orographic effects and other factors push average annual rainfall to 34 inches. Sunshine is abundant, humidity is low, and snowfall ranges from light in the low desert to heavy in the high country.

There are two rainy seasons -- July through September and December through March. As in many arid regions, precipitation varies in volume and intensity from year to year and from area to area, especially in summer. Summer thunderstorm activity, though intense, is typically sporadic in aerial coverage and duration. It accounts for about half the total precipitation and is derived from moisture picked up over the Gulf of Mexico. Mid-winter storms may persist for several days and are more general in their coverage. The moisture delivered during winter events is derived from the Pacific Ocean (National Park Service, 1995).

Ephemeral stream flow in the Tucson Basin is triggered by summer thunderstorms, and occasionally by prolonged periods of winter precipitation. Stream discharge varies rapidly in response to thunderstorms, and the duration of flow is typically no more than one or two days. Frontal-induced winter stream flows, acting in response to the more general rainfall, are less flashy and may last for several days (Burkham, 1970).

FIGURE 1: Location of Saguaro National Park's Tucson Mountain and Rincon Mountain Districts.



GEOLOGY

The Tucson Basin comprises a portion of the upper Santa Cruz Basin, a valley draining to the northwest and bordered by narrow, rugged mountain ranges. The Tucson Basin's northeastern boundary is formed by the Santa Catalina and Rincon Mountains, and its western boundary is formed by the Tucson Mountains (Upper Santa Cruz Basin Mines Task Force, 1979). Tucson is centrally located within the 1,000 square mile Tucson Basin and has an elevation of 2,300 feet. A geologic barrier near the town of Cortaro provides a reasonable dividing line between the ground waters of the upper and lower Santa Cruz Basins (Burkham, 1970). The Rincon Mountains reach a maximum elevation of 8,666 feet while the Tucson Mountains reach only 4,687 feet.

Rincon Mountain District and Coronado National Forest encompass the Rincon Mountains. The Rincons are composed of folded and foliated banded gneiss, schist, and granite of Precambrian age, draped over at their base by Tertiary and younger alluvial and colluvial deposits. Often the colluvium forms a thin cover over pediment surfaces. The TMD and adjoining Tucson Mountain Park cover most of the Tucson Mountains which are dominated by Permian and Cretaceous limestone, arkose, red beds, and Tertiary intrusives and volcanics. Quaternary gravels are also present and cover most of the pediments (Streitz, 1962). The lower flanks of the Tucson and Rincon Mountains are covered by terrace deposits or other alluvium ranging from 100 feet thick in RMD to 400 feet thick in TMD (National Park Service, 1995).

The Tucson Basin is filled with the fluvial, lacustrine, and debris flow deposits derived from the erosion of the surrounding mountains and ranges farther up the drainage. The center of the basin is a dissected graben structure where massive accumulations of fine-grained sediments and evaporites are present (Leake and Hanson, 1987). Alluvial fan deposits occur along the perimeter of the basin, while river channel and flood plain deposits are common in the center of the basin and make up the larger proportion of the fill. The basin deposits are typically Tertiary and Quaternary in age, and may be as much as 8,000 feet thick (Streitz, 1962). Geologic factors controlled the formation of the valley fill and determined the textural and structural relationships of the basin sediments. The characteristics of the sediments in turn control the occurrence and movement of ground water in the basin (Kidwai, 1957).

SOILS

Standard soil surveys were completed for both districts in 1987 by the Soil Conservation Service. Soils are typically shallow, coarsely textured, and well drained on the mountain slopes. Soils on the bajada are alluvial and contain distinct areas of sandy or rocky soils with equally distinct plant associations (National Park Service, 1995). These soils lend themselves to rapid recharge, although recharge normally does not occur outside stream channels because antecedent soil moisture is usually very low, evaporation is very high, and rainfall amounts are insufficient to push the wetted front to ground water depths. An impermeable layer of caliche frequently forms at this depth, which can limit plant establishment and growth. Because alluvium within stream channels, fans, and bajadas are very permeable, streams spread out and rapidly lose flow as they leave the steep mountain gradients and enter the alluvial flats (Osterkamp, 1973a).

HYDROLOGY

The major drainage system in the Tucson Basin is the Santa Cruz River and its tributaries. The Santa Cruz heads in the San Raphael Valley and flows south into Mexico (Figure 1), then turns north and re-enters the United States at Nogales, from where its usually dry channel leads north-northwest through Tucson to join the Gila River ten miles southwest of Phoenix. The Santa Cruz is ephemeral within most of the Tucson Basin (except for a few miles below the sewage treatment plant), and a large precipitation event is required to produce flow all the way to its confluence with the Gila River. The east flank of RMD drains into the San Pedro River, while the west flank of the Tucson Mountains drain into Brawley Wash and the Avra Valley.

Watersheds within the two districts are typically small, containing first, second, and third order perennial interrupted, intermittent or ephemeral streams. Because the districts bound topographic highs, surface drainage flows from the park to adjoining lands (Figures 2 and 3). The only exception is the Rincon Creek drainage, which covers about one

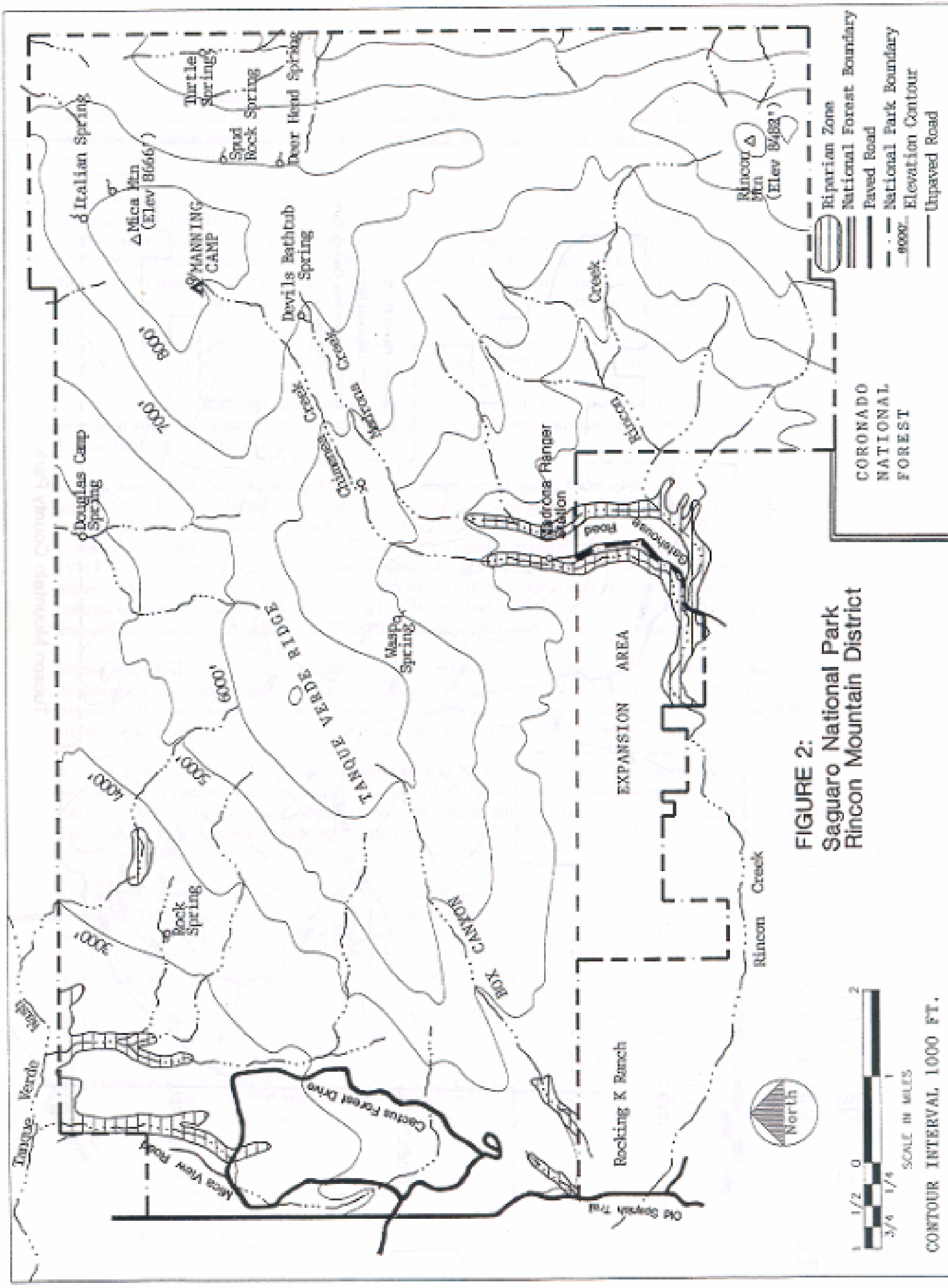


FIGURE 2:
Saguaro National Park
Rincon Mountain District

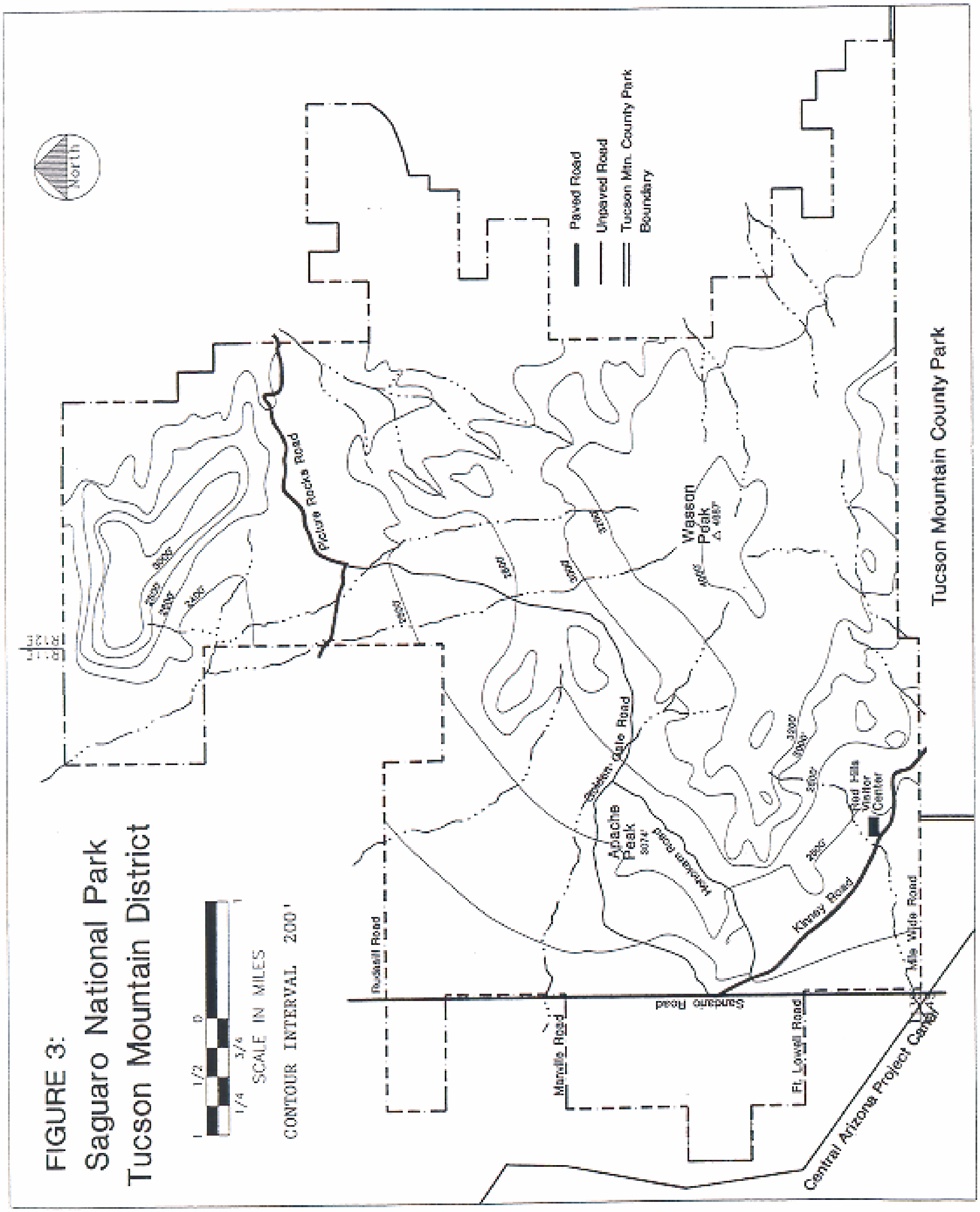


FIGURE 3:
Saguaro National Park
Tucson Mountain District
SCALE IN MILES
CONTOUR INTERVAL 200'
North
Paved Road
Unpaved Road
Tucson Mtn. County Park Boundary
Picture Rocks Road
Wasson Peak
Apache Peak
Golden Gate Road
Kinney Road
Red Hills Visitor Center
Mile Wide Road
Sandario Road
Rudasill Road
Manville Road
Ft. Lowell Road
Central Arizona Project Canal
Tucson Mountain County Park

third of the Rincon Mountain District. Short reaches of Rincon, Madrona, and Chiminea creeks flow from park land, across private land, then enter the NPS expansion area on the south side of RMD. Rincon Creek is ephemeral within the expansion area; however, ground water is near the surface and the adjacent flood plains contain high quality riparian habitat.

Precipitation in the districts contributes significantly to the recharge of adjoining basins via stream channel and mountain front transport and infiltration mechanisms. Total basin recharge results from direct penetration of rainfall on the basin floor (very minor), mountain front recharge, infiltration from stream beds, leakage from waste water discharge, and minor contributions from irrigational and industrial seepage (Burkham, 1970; Osterkamp, 1973a). As displayed in Figure 4, recharge along the mountain front is primarily from infiltration along small stream channels and from subsurface seepage of water from the consolidated rocks composing the mountains.

Most of the recharge to the Tucson Basin comes from stream channel losses during periods of stream flow. Studies of annual runoff versus annual recharge show that, on average, 70% of the water flowing down channels feed ground water reservoirs; the rest flows out of the Tucson Basin (Burkham, 1970). Stream channel losses averaged 47,000 acre feet per year. On average, the amount of infiltration water that reaches the ground water reservoir is probably more than 90%. Using these and other estimates, the safe yield commonly used in planning calculations for the Tucson Basin is 45,000 acre feet per year (Dotson et al., 1990).

Ground water in the Tucson Basin generally occurs under unconfined or water table conditions. Permeability is highest in the center of the basin where the fluvial deposits are coarse and composed of gravel, gravel and sand, and well-sorted sand. Ground water velocities range from 10 to 100 feet per year near the boundaries of both units; however, continued drawdown may have increased the hydraulic gradient and thus the flow velocities (Osterkamp, 1974). Flow lines are typically away from the national park's districts. The bedrock is generally treated as impermeable for most water resource problems relative to the alluvial aquifer because of the high permeability contrast between the bedrock and the alluvial fill. Water levels in the consolidated bedrock, which contain small amounts of water per unit area, are at or near the surface in the higher country (Osterkamp, 1973b)

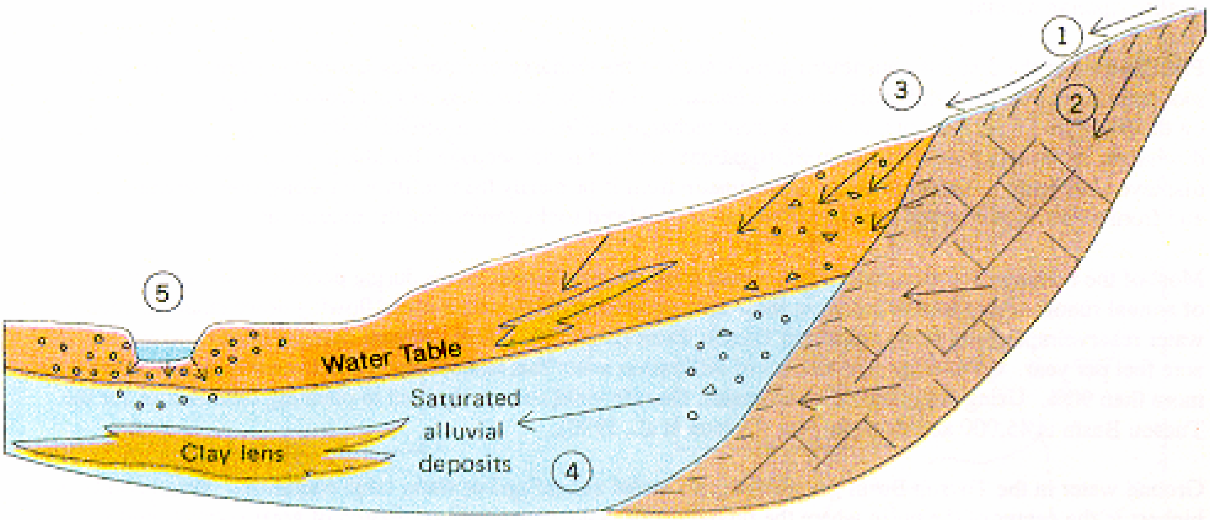
Within individual basins, water in the fill deposits moves from the mountain front toward the basin axis where it discharges at land surface, mixes with existing underflow, or is intercepted by well fields. In general, the alluvial deposits in the basin are hydraulically connected to form a single aquifer system. Ground water is near the land surface along perennial streams but may be more than 300 to 800 feet deep near the mountain fronts (Cordy, 1994).

Agriculture was the largest user of ground water prior to 1975, after which municipal withdrawals assumed the largest portion. Tucson Water currently pumps about 100,000 acre feet of ground water each year from the Tucson Basin and Avra Valley (Figure 1), which exceeds the average rate of recharge. Recent state legislation requires the Tucson Active Management Area to attain safe yield by the year 2025. This mandate appeared reachable with the completion of the Central Arizona Project (Dotson et al., 1990).

The Central Arizona Project (CAP) delivers Colorado River water to portions of central Arizona. Tucson contracted 148,000 acre feet per year of CAP water from the Bureau of Reclamation, based on the population and demand. Use of CAP water will allow Tucson to reach safe yield at its forecast growth until 2023 (Dotson et al., 1990). However, despite the careful planning and projections, very little of the CAP allocation is presently being used and ground water mining continues to occur in both the Tucson Basin and Avra Valley.

Between 1947 and 1985, the majority of the Tucson area experienced ground water declines ranging from 40 to 80 feet (Bureau of Reclamation, 1986). From 1940 to 1985, water levels declined by more than 100 feet throughout most of the Avra Valley (Cuff and Anderson, 1987) resulting in increased pumping costs. As the aquifers are dewatered, the basin's land surface subsides and surface fissures occur at the basin margins, causing damage to agricultural facilities, roads, utilities and structures. Drawdown also results in decreased transmissivity as permeable sediments are dewatered, and increased vertical affective stress causes compaction of the aquifer system (Anderson, 1988).

FIGURE 4: Aquifer recharge diagram for the major basins near Saguaro National Park



(1) Mountain stream flows in response to precipitation from storm.

(2) In the mountains the stream loses small amounts of water through joints and cracks in the consolidated rocks. The water moves toward the valley and seeps into the sand, gravel, and silt that fill the valley.

(3) Mountain stream flows out of mountains onto permeable sand and gravel filling the valley. Stream loses large amounts of water by infiltration.

(4) Under the force of gravity, water in the saturated alluvial deposits of silt, sand, and gravel moves slowly to the lowest point and eventually to the outlet of the valley.

(5) Normally dry desert stream is perched above water table. When stream does flow, it rapidly loses water by infiltration to the permeable sand and gravel of the channel. The water moves downward to the aquifer.

[Source: Osterkamp, 1973a]

Ground water quality problems are typically local in nature involving natural factors such as high total dissolved solids, natural and anthropogenic combinations such as high nitrates where sewage effluent recharges the aquifer, and anthropogenic contaminants such as trichloroethylene from leaking jet fuel storage tanks (Leake and Hanson, 1987; Osterkamp and Laney, 1974). Fluoride is also found in levels exceeding drinking water standards in limited areas of the Tucson Basin.

PHYSIOGRAPHIC HISTORY

Geology, soils, hydrology, climate, and other physical factors define the foundation upon which ecological communities evolve and are sustained. In the Tucson area, historic accounts and research investigations indicate hydrologic parameters, as well as vegetative assemblages, have changed significantly in the past 100 years. It is important to have a sense of the nature and magnitude of these changes before discussing the area's ecology or the park's issues.

Smith (1910) provides the following account of changes in a portion of the Tucson Basin in a report entitled *Ground Water Supply and Irrigation in the Rillito Valley:*

The oldest known effort at settlement in the Rillito Valley was that of an Arkansas pioneer who cleared a small area of bottom land just east of Fort Lowell in 1858. The entire valley was at that time unbroken forest, principally of mesquite, with a good growth of grama and other grasses between the trees. The river course was indefinite, a continuous grove of tall cottonwood, ash, willow, and walnut trees with underbrush and sacaton and galleta grass, and it was further obstructed by beaver dams.

In the fall of 1872 the U.S. Army post was moved from the military plaza in Tucson to the junction of Pantano Wash and the Rillito. There was a great demand for hay and the grass was cutoff with hoes to supply the post on large contracts. A few years of such cropping sufficed to kill it. Cattle were brought into the country during the seventies and roamed the valley and hills, destroying the root grasses and wearing trails which later became rivulets in times of rain, increasing the runoff of water to the river.

New and unusual floods cut out a wide channel, washed the big cottonwoods away, and exposed the white sand. The amount of total runoff from the land must have increased very greatly, and yet meanwhile the permanency of the small surface flow in the river was decreased. The general affect [*sic*] of settlement was to increase the magnitude and severity of the floods and, also, the length of the totally dry seasons. In the Pantano, the first real flood to reach the Rillito occurred in 1881, but it was much spread out over the valley and not until in the 90s was the present deep broad wash with vertical banks eroded.

A mesquite bosque, located in the Santa Cruz Valley near Tucson, is described in Arnold's (1940) summary of early literature. In 1902: "the bottom lands on either side of the river are covered, miles in extent, with a thick growth of giant mesquite trees. This magnificent grove is included in the Papago Indian Reservation, which is the only reason for the trees surviving as long as they have, since elsewhere every mesquite large enough to be used as firewood has been ruthlessly cut down." By 1917, a policy of deforestation reduced the Papago stand as well.

Hastings and Turner (1962) conducted an exhaustive review of historical accounts, photodocumentation, and scientific evidence in their book *The Changing Mile - an Ecological Assessment of Vegetation Change with Time in the Lower Mile of an Arid and Semi-Arid Region*. They estimated the change from sluggish streams running through a marshy, largely unchanneled valley to a steep-walled ephemeral trench began around 1890. After the 1890s, where streams formerly ran consistently throughout the year, the flow became intermittent, leaving the new channel dry over much of its length most of the time. They noted that malaria, once a major plague, disappeared along with the marshes, the beavers, and the fish. As washes adjusted their elevations to those of the main streams, the valley floors became dissected and re-dissected (Hastings, 1959).

After the river valleys, the grasslands of the desert region appear to have changed the most. Other accounts reported by Hastings and Turner (1962) state, by 1892, over-stocking of cattle, combined with below normal rains, caused the loss of cattle in "staggering numbers...dead cattle lay everywhere. You could actually throw a rock from one carcass to another. Thousands of square miles of grassland, denuded of their cover, lay bared to the elements." The authors stated: "The cropping unquestionably weakened the old plant communities, leaving them open to invasion; it unquestionably upset the balance between infiltration and runoff, in favor of the latter" (Hastings and Turner, 1962).
However, not all researchers come to the conclusion that land use in the arid regions of the southwest resulted in the arroyo cutting and other changes in the area's hydrology. Leopold (1994) noted arroyo cutting in the geologic past in many western valleys and recognized that down cutting occurred in the late nineteenth century in western basins where cattle grazing was relatively nonexistent. Leopold implicates climatic change as the primary causal agent triggering downcutting, but states that overgrazing greatly accelerated the process. Hastings and Turner (1962) conclude: "What caused the events of the 1880s? Not large-scale cattle raising certainly, and perhaps not climate; probably the combined impact of the two."

Whatever the cause, looking over the dry desert of the Santa Cruz Valley today it is difficult to imagine this area as marshy and dominated by riparian forests and grasslands, and easy to comprehend the importance of any riparian habitat that remains.

ECOLOGY

Tucson Mountain District ranges from 2,165 feet to 4,687 feet in elevation and comprises the Lower Sonoran Desert Scrub and the Upper Sonoran Desert Grassland vegetative communities (National Park Service, 1995). Within RMD, elevations and vegetation types rise from Desert Scrub in the Lower Sonoran Life Zone at 2,654 feet through the Upper Sonoran Desert Life Zone, containing Desert Grassland, Oak Woodland, and Oak/Pine Woodland. It continues through a Transition Life Zone of Pine Forest to a Canadian Life Zone of Montane Fir Forest at the maximum elevation of 8,664 ft. (Shand and Underhill, 1985). There are no endangered plant species presently known in Saguaro National Park (National Park Service, 1995). Characteristic exotic plants include Russian thistle, filaree, tamarisk, African daisy, rummex, and several species of grasses including Bermuda grass, natal grass, fountain grass, buffle grass, four species of love grass, and three species of brome.

Where hydrologic conditions are favorable, within each life zone are distinctive riparian communities, which by their nature require far greater amounts of water than other terrestrial ecosystems (Snyder, 1995). Ground water is often the critical source of supply to maintain the riparian zone, particularly in this climate of low rainfall and high evapotranspiration (Jemison, 1989). The underlying water table serves to maintain the plant communities during dry periods and supports the productivity and character of the riparian ecosystems (Groeneveld and Griepentrog, 1985). Mesquite, willow, sycamore, cottonwood, ash, and hackberry are a few of the riparian species referred to as phreatophytes in the southwest because they are capable of, and in fact rely on, the utilization of ground water in their metabolism. A riparian woodland may contain only one or a combination of phreatophytes, and may be found at any elevation in southern Arizona (Gavin, 1973).

Riparian ecosystems have been recognized as some of the most important and most endangered ecosystems in the desert southwest (Johnson and Haight, 1985). Drainages formed by intermittent and ephemeral streams, and their associated ecosystems, provide critical habitat in arid and semi-arid desert regions. The wildlife values of the riparian forests include sources of food, cover, and nesting and denning sites. Mesquite is probably the most valuable food source because of the beans it produces (Arnold, 1940). As an example of cover, Gavin (1973) recorded or trapped fifteen species of mammals in a riparian area, and Anthony (1972) determined that mule deer become nocturnal during the heat of summer and spend the daylight hours bedded down in mesquite bosques.

Riparian habitats appear especially crucial to avian populations. Bird populations are very low in the open desert (0 - 37 pairs per 100 acres) but may reach 108 pairs per 100 acres in riparian areas where there is a greater diversity of vegetation (Gavin, 1973). Avian censuses conducted in riparian plots at SAGU averaged 19.67 species per census with 167 individuals, in contrast to upland averages of 11 species and 47.5 individuals per census. Thus the riparian plots supported almost twice the number of species and 3.5 times the number of individuals as upland plots. Also, 13 species were found exclusively in the riparian plots (almost ½) while none were found only in the upland plots.

This indicates that all avian species depend on riparian areas at some time for life-supporting functions (Johnson and Haight, 1985). Johnson and Haight (1991) also determined that stream channel and wash vegetation is important to migrating bird life traversing the desert, and to northern birds wintering in the southwest.

The balance between ground water levels, dependent phreatophytes, and associated wildlife may be particularly sensitive to alteration. Lacey et al. (1975) state that ground water declines resulting from agricultural or urban pumping was most directly responsible for recent vegetative losses in southwest riparian areas. Judd et al. (1971) studied the lethal decline of mesquite on the Casa Grande Ruins National Monument. They noted that significant water table drawdown resulted in the loss of a riparian mesquite bosque and its associated faunal community. Mesquite taproots are generally 30 feet long. Where the water table exceeds 40 feet in depth, closed canopy mesquite forests do not exist, but only the open stands of shrub or savannas. Therefore, if the water table is lowered much below 40 feet, mesquite will not be able to survive in the tree-growth form as found in the bosque community.

Smaller water table declines or increased fluctuation can also negatively impact phreatophytic vegetation. Water stress necessitates stomatal closure and loss of carbon fixation resulting in reduced productivity (Groeneveld and Griepentrog, 1985). This is especially true of riparian species since they are adapted to moist environments and are, as a group, relatively intolerant to drought stress. Repeated or prolonged stress, especially during dry periods, may therefore induce severe impacts to riparian vegetation. As stated by Gavin (1973): "Ground water development, while necessary for man's activities, should be sensitive to potential impacts and be planned accordingly. The potential for degrading riparian areas and subsequent erosion is widespread in western North America."

WATER RESOURCE ISSUES

WATER TABLE DECLINES

As stated by Cordy (1994): "The major water issue in Arizona is the imbalance between the quantity of water consumed and the quantity that is recharged back to the aquifers." As a result, ground water declines are well documented in the Tucson Basin and Avra Valley. Water table declines have the potential to affect SAGU's resources through:

1. Loss of phreatophytic vegetation;

2. Decreased capacity of water supply wells;

3. Aquifer compaction and land subsidence; and,

4. Fracture dewatering within bedrock and resulting loss of recharge to springs and seeps.

1. Loss of phreatophytic vegetation:
Water level declines in riparian areas can change the nature and reduce the quality of the habitat provided by phreatophytic vegetation. With the continued loss of riparian habitat in the Tucson Basin, preservation of riparian habitat within the park becomes increasingly critical. Too little is known about the interactions between ongoing ground water withdrawals, future developments, and the physical hydrology and biological processes active within the park's riparian areas. A successful preservation scheme must include some means of quantifying and offsetting potential water level declines if these declines threaten to impact riparian resources.

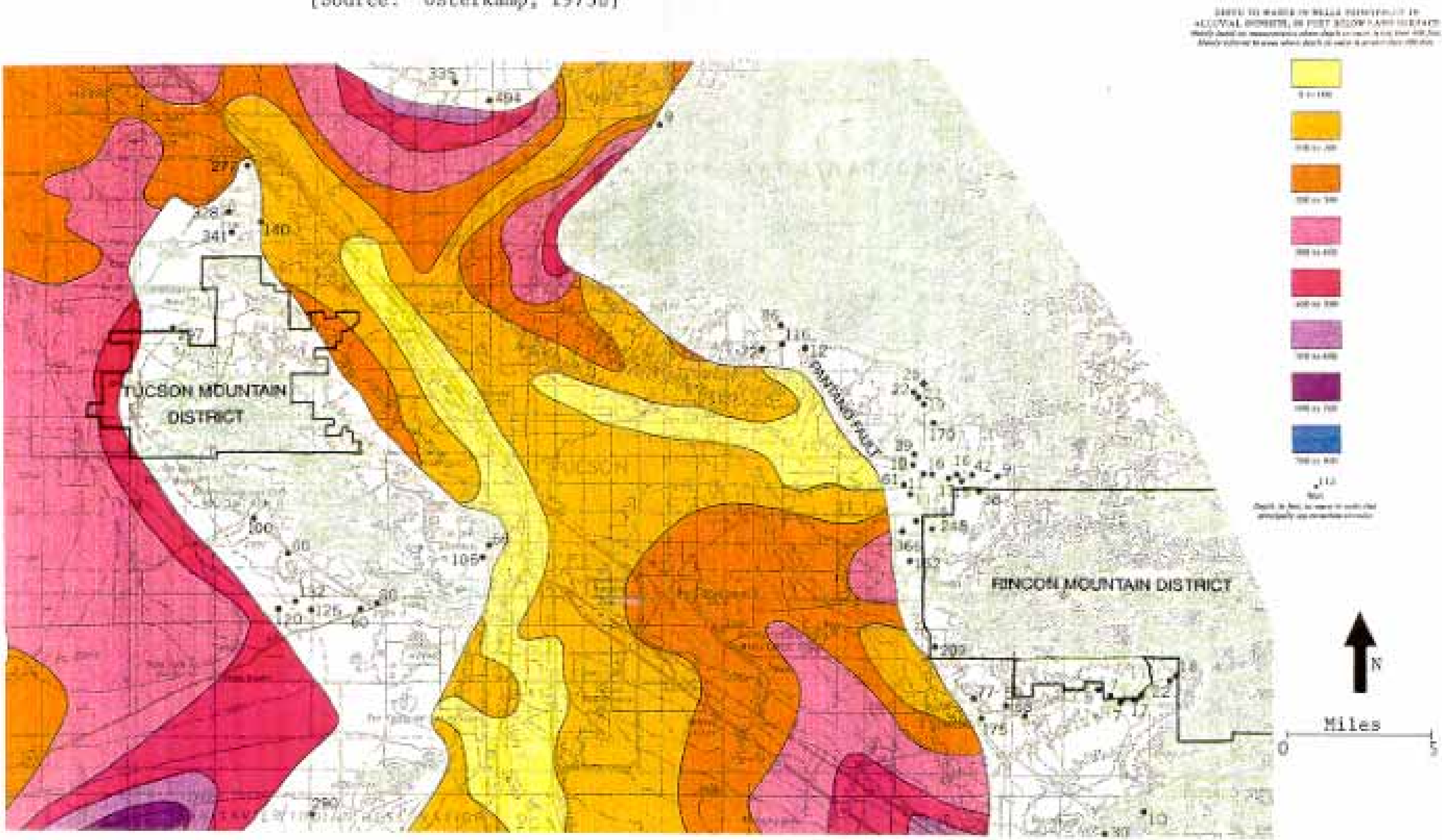
Three riparian areas within RMD are situated in areas susceptible to water level declines. TMD, because of its smaller catchment basins, minor orographic rainfall, and differing geology, does not contain any areas mapped with riparian vegetation. The riparian areas of concern within RMD are shown in Figure 2, and include Rincon Creek near the NPS expansion area, lower Box Canyon, and the lower reaches of the drainages feeding Tanque Verde Wash. Riparian habitat is also present at higher elevations along mountain drainages, but these areas are not considered readily susceptible to water table declines. With the expansion of Tucson, and proposals for major developments near these three areas, new well fields could lower water tables resulting in the loss of phreatophytes and their associated value to the park's wildlife.

The ground water reservoirs supporting the riparian areas within RMD are not directly connected to the Tucson Basin aquifer. As shown in Figure 5, the major aquifer of the Tucson Basin lies outside the boundaries of RMD. This is important because the drawdown within the Tucson Basin is, in most areas, already sufficient to place the water table beyond the depth where phreatophytic vegetation can access and utilize this resource. Osterkamp (1973b), reported depth to water in wells in the Tanque Verde Wash and Rincon Creek areas is often less than thirty feet, and this is supported by the riparian vegetation mapped in these areas. The thickness of the saturated alluvium in the three areas varies greatly, but the overall storage capacity is orders of magnitude less than the saturated sediments within the Tucson Basin, and well field development up-gradient from the Pantano Fault could have an immediate and pronounced effect on water table elevations.

Burkham (1970) determined that within Tanque Verde Wash and Rincon Creek, the thickness of the saturated alluvium varies from 20 to over 100 feet thick. The depth to ground water below Tanque Verde Wash was five to 30 feet, and from 10 to 100 feet under Rincon Creek's channel. He noted that, in general, alluvial thicknesses and ground water depths are least near the mountains. Seepage measurements performed by Burkham (1970) revealed relatively low infiltration rates along Rincon Creek within the NPS expansion area, indicating small thicknesses of permeable alluvium and interferences with shallow ground water. In lower reaches of Rincon Creek, infiltration rates were extremely high as a result of the increased thickness of alluvial sediments and the spreading out of the flow over a broader channel and flood plain.

FIGURE 5: Location of the major basin aquifers* adjacent to the two districts of Saguaro National Park

[Source: Osterkamp, 1973b]



*Colored portions of map represent areas of significant ground water storage within major basin aquifers. Area between the two districts represents the Tucson Basin aquifer, while the area to the west of Tucson Mountain District represents the Avra Valley aquifer.

In Halpenny's (1985) evaluation of 12 wells (all east of the Pantano Fault and up-gradient from the Tucson Basin) in lower Rincon Valley, he determined that there has been no consistent drawdown of water levels through time, and concluded the Pantano Fault (shown in Figure 5)prevents water level declines in the Tucson Basin from affecting the levels in the Rincon Valley. Halpenny noted water levels within wells along the lower reaches of Rincon Creek fluctuated with wet and dry periods. Therefore, any monitoring well strategy proposed for Rincon Valley should be in place long enough to demonstrate the magnitude of the inherent seasonal flux before trends could be superimposed on future water levels.

Ray Turner (U.S. Geological Survey, Retired, pers. comm., 1996)described recent developments along Tanque Verde Wash where drawdown has apparently impacted the riparian community therein. Tucson Water located municipal wells outside the Tucson Basin and within the saturated alluvium that lies between the Rincon Mountains and the Tucson Basin along Tanque Verde Wash. When the wells were activated, cottonwood trees began to die, and public concern caused the city to halt pumping. Because of the increased demand for water in Tucson, and the moratorium on the use of CAP allocations, Tucson Water is again expanding its well field into the Tanque Verde area.

To the south of RMD, another water development project, the Rocking K Ranch, is proposed for lower Rincon Creek. Developers anticipate having 9,000 residents within the Rocking K, and have been granted a permit by the Arizona Department of Water Resources to withdraw 4,400 acre feet/year (3,927,788 gal/day) from the underlying alluvial aquifer (Halpenny, 1985). There is clear potential for this magnitude of extraction to impact park resources in the Rincon Creek and Box Canyon areas through depletion of ground water reserves and subsequent declines in riparian water tables.

Recommendation:
To address the issues connected to declining water tables, a Project Statement and Technical Assistance Request have been written in consultation with SAGU managers and are included as Appendices in this document.

Appendix A contains a recently funded project statement intended to inventory surface water resources and ground water dependent riparian communities in SAGU. The inventory will locate and characterize each water feature using standard hydrologic parameters. Measurements and descriptions will rank water sources and zones of ground water influence in terms of habitat importance and potential sensitivity to water table declines and other factors. This hydrologic information and analysis, used in conjunction with ongoing wildlife and vegetation studies, will provide the basic link between physical processes and biological systems needed to initiate management actions to protect aquifers and ground water resources that support its unique floral and faunal habitats.

Appendix B contains a technical assistance request to address the issues connected to declining water tables. The request seeks assistance from a ground water hydrologist with the Water Resources Division familiar with the interactions between water tables, well field development, and phreatophytic vegetation in a western landscape. Specific actions recommended include:

•Background investigations to locate and interpret water level data available in the area which could help quantify present ground water conditions and seasonal fluctuations of water tables.

•Amount and quality of phreatophytic vegetation within the riparian zones shown in Figure 2 and their relative dependence on ground water.

•Hydrologic connectivity between areas of potential development and low elevation riparian areas.

•Map relationships (where data exists) between water levels, alluvium, and phreatophytic vegetation (i.e., what depth to ground water supports riparian vegetation and how thick does the saturated alluvium have to be to support a perennial aquifer).

•Development of a conceptual model of ground water behavior and an estimate of the potential for water table declines to extend into the park.

•Recommendations as to whether or not a ground water monitoring scheme should be developed to monitor potential problem areas, and, if necessary, how the monitoring strategy should proceed. If a monitoring program is recommended, assist SAGU in funding and implementing the monitoring scheme.

•Guidance to park managers involved in purchasing lands within the NPS expansion area concerning the appropriate water rights investigations and purchases needed to protect ground water and riparian resources.

2. <u>Decreased Capacity of Water Supply Wells:</u>
Deep wells provide water for both districts. RMD draws over one million gallons annually from a 500 feet deep well located on government property one mile west of the boundary. As inferred from Figure 5, the production well lies outside park boundaries because SAGU does not overlie the Tucson Basin aquifer anywhere within its boundary. A 560 feet deep well within TMD provides 700,000 gallons per year from the saturated alluvial deposits within the Avra Valley. This well is located in the extreme southwest corner of TMD and taps the Avra Valley aquifer. The water is not treated at either unit but passes all state tests for public drinking water sources (National Park Service, 1995).

Presently, SAGU management is negotiating with Tucson Water to connect RMD with the city's distribution system, and would no longer have a direct need for the well in the Tucson Basin. This would alleviate any potential concern over decreased capacity affecting RMD. A map of measured water level declines in Avra Valley from 1940 to 1978 shows about 110 feet of drawdown at TMD's southwest boundary near the location of the water supply well. Using simulation modeling, the same area is predicted to undergo between 200 and 250 feet of water level decline by the year 2025, as compared to the 1940 level (Hanson et al., 1990).

<u>Recommendation:</u>
Relative to the negotiations with Tucson Water, if an analysis of historic depth to water information indicates the water level in the RMD well has declined significantly, and Tucson Water is the most active user of ground water in the vicinity of the RMD well, NPS could potentially negotiate with Tucson Water and argue that they have impacted the RMD well and therefore should construct a distribution system or provide water at a lower cost. The Water Rights Branch of the Water Resources Division should be contacted if SAGU decides to pursue this matter.

The technical assistance request in Appendix B also addresses the need for a review of any water level records available for TMD's well. This review is intended to insure an abundant supply of ground water is available to serve this district, forecast any potential problems, and develop a database for use in the Santa Cruz adjudication. In addition, it should be determined if TMD should be monitoring the water level of its supply well, and if so, how to proceed.

3. <u>Aquifer Compaction and Land Subsidence</u>: According to Cordy (1994) major land subsidence has already occurred in the Phoenix area where water level declines have been in excess of 500 feet. Aquifer compaction has the potential to damage park infrastructure, such as water, sewage, and other distribution lines, roads, and buildings. However, the units are, for the most part, not situated over the alluvial basins where settling would occur. In fact, RMD does not overlie the Tucson Basin alluvial aquifer at any location (Figure 5). The only areas with a potential for subsidence are the extreme eastern and western portions of TMD.

<u>Recommendation</u>:
Hanson (1989) shows land subsidence of 0.5 feet has already occurred in the Tucson Basin, and 1.1 feet in Avra Valley. Maps of potential maximum land subsidence show no significant subsidence near the boundaries of TMD or its well. It appears drawdowns in excess of 250 feet initiate the compaction process, which can then occur rapidly after reaching this threshold level (10 feet of compaction can be expected with 350 feet of drawdown). Compaction occurs when water level declines cause vertical pressures to exceed the preconsolidated-pressure threshold of the alluvial deposits. Because large amounts of drawdown are required to initiate compaction, it is recommended that no action be taken regarding this issue until water level declines begin to approach the 250 feet threshold. Technical assistance is required to review water level data in wells and water level declines near TMD, and determine if the recommendation stated above is adequate to address this issue.

4. Fracture dewatering of springs and seeps:
Part of the Tucson Basin and Avra Valley's recharge arrives via fracture transport from the mountain front as described by Osterkamp (1973a) in the caption of Figure 4. Therefore, fracture water and basin water are hydraulically connected to some degree. Drawdown of water levels in Tucson Basin, and the smaller aquifers in Tanque Verde Wash and Rincon Creek Valley, could result in decreased back pressure on mountain fracture systems and the loss of springs or seeps dependent on a fully saturated fracture to provide surface flow. The hydraulic behavior of fracture connectivity is speculative, and is more a hypothesis than a working model.

Recommendation:
The prescribed course of action is to inventory mountain water sources as described in Appendix A. An inventory, with return trips and repeat measurements, would allow SAGU managers to be aware of changing water conditions should they occur. If the loss of water sources or related attributes is noted, efforts could then be undertaken to determine if a linkage could be made between basin water level declines and fracture dewatering. SAGU might then use the Santa Cruz adjudication process to take some form of protective action.

WATER RIGHTS ADJUDICATION

The United States (National Park Service) holds both State appropriative and Federal reserved water rights at Saguaro National Park. State water rights in Arizona are based on the Doctrine of Prior Appropriation. Under this Doctrine, the party who first utilizes water for a beneficial use has a prior right to use, against all other appropriators, e.g., "first in time, first in right." The water must be put to beneficial use as defined by the State. In Arizona, beneficial uses include irrigation, domestic, stock watering, municipal, commercial, industrial, mining, recreation, fish and wildlife, and other uses. An appropriative water right is a property right; under State law it can be bought, sold, and its place of use, purpose, and point of diversion may be changed without loss of priority provided there is no injury to the water rights of others.

Federal reserved water rights arise from the purposes for which the land was reserved by the Federal Government. When the Federal Government reserves land for a particular purpose it also reserves, by implication, enough water unappropriated at the time of the reservation as is necessary to accomplish the purposes for which Congress or the President authorized the land to be reserved, without regard to the limitations of State law. The rights vest as of the date of the reservation, whether or not the water is actually put to use, and are superior to the rights of those who commence the use of water after the reservation date. General basin-wide adjudications are the means by which the Federal Government claims its reserved water rights. The McCarran Amendment (66 Stat. 560, 43 U.S.C. 666, June 10, 1952) provides the mechanism by which the United States, when properly joined, consents to be a defendant in an adjudication.

Once adjudicated by the State, the water rights of the United States, reserved and appropriated, fit into the State priority system along with those of all other appropriators. In general, when it is brought into a general adjudication, the United States is given its only opportunity to assert its claim to water rights. Unless legally absent from the proceedings, it is generally understood that failure to assert a claim to water rights in such a proceeding may result in forfeiture of these rights.

In 1987, in a general water rights adjudication of the upper Santa Cruz River, the United States Department of Justice, on behalf of the National Park Service, submitted both Federal reserved and State appropriative water right claims for Saguaro National Park. State appropriative water rights were claimed for domestic, municipal, fire protection uses and wildlife purposes. Federal reserved water rights were claimed for water necessary to fulfill reservation purposes including securing favorable conditions of surface water flow and ground water levels necessary to preserve objects of scientific interest; to secure the benefits of wilderness; and, to provide for the administration of and visitation to the park.

In addition to these claims, non-NPS (alien) claims for rights to water from sources within and near Saguaro National Park occur. The status and validity of these claims, as well as their potential impacts on management of the park resources are unknown (D. McGlothlin, NPS Water Resources Division, pers. comm., 1996; B. Hansen, NPS Water Resources Division, pers. comm., 1996).

Recommendation:
The Federal reserved water rights have not yet been quantified at SAGU. A surface and ground water rights and resources inventory is necessary to provide documentation required in the adjudication. In addition, natural and cultural resource studies need to be conducted to determine the dependence of the water-related resource attributes on surface and ground water in Saguaro National Park. Specific studies might include investigations documenting ground water declines in SAGU and the potential affect such declines might have upon riparian vegetation near channels, springs and seeps, water supplies, and aquifer compaction and land subsidence. Quantification of NPS water rights may provide a legal mechanism to assure the protection of water and water-related resource attributes and may play an important role in resource management decisions.

As part of the resource inventory, the location, discharge, and other information gained from the *Water Source and Riparian Inventory* described in Appendix A could provide key information required in the adjudication. If appropriate, newly identified water sources in the San Pedro Basin could be added to the recognized list of adjudicated sources. As the elements of the inventory (Appendix A) and technical assistance request (Appendix B) are implemented, it will be crucial to coordinate all aspects of the work with members of the Water Rights Branch to assure data gathered supports the needs of the adjudication process.

LACK OF BASIC HYDROLOGIC DATA

When the Arizona Game and Fish Commission began compiling a resource base of perennial stream reaches within the state, they contacted SAGU for stream flow information for both districts. Unfortunately, the staff was unable to provide complete locations and extent of perennial stream reaches because an inventory of the hydrologic character of SAGU's streams has not been done. The park also lacks information concerning the perennial nature of springs and seeps, an inclusive map showing their locations, and what unique plants or animals might be found in association with them. Knowledge of water sources is fundamental to understanding the behavior of wildlife dependent on perennial water sources during dry periods.

Recommendation:
Appendix A contains a proposal to conduct an inventory of water sources and riparian areas. Analysis of this information should provide most of the basic hydrologic data needed to more effectively manage SAGU's aquatic resources and the terrestrial species dependent on perennial surface water. Once the physical parameters are defined and a cursory examination of the biology conducted, especially favorable habitat areas should be examined more closely by plant ecologists and aquatic biologists to further refine the inventory. The inventory and related fieldwork will provide a useful characterization of the ecological diversity and function associated with these unique desert habitats.

MINING AND MINERAL DEVELOPMENT

Both districts of Saguaro National Park have had some mining activity. However, mining was never widespread or intensive in RMD (Clemensen, 1987). Small scale lime kiln operations occurred between the 1880s and 1910s. The Loma Verde Mine reached 350 feet in 1902, but was not included on a list of mines just five years later. In the mid-1930s, the Civilian Conservation Corps filled in 30 prospect holes in RMD.

Mining activity was more pronounced in TMD, where there are 150 mine shafts with associated tailings piles. Most of the abandoned mines are within designated wilderness areas. The two largest operations, the Gould and Mile Wide mines, have quite large tailings piles and some yellow staining in stream channels up to 1/4 mile below the piles. However, because the streams in TMD are only ephemeral, there is no possibility of impacting aquatic communities with mine land runoff. Although there is very little vegetation on these large refuse piles, vegetation below the piles appears to be little affected by runoff.

Ground water contamination by leaching from the tailings piles is unlikely because the rainfall/evaporation ratio is low and diffuse recharge provides little input to the underlying aquifers. The conclusion drawn by the Upper Santa Cruz Basin Mine Task Force (1979) was that ground water contamination from mining activities could not be detected in either the Tucson or Avra Valley basins, even from large active mines. The only potential for contaminant migration is during periods of intense thunderstorms when surface runoff could be generated from the tailings piles. During these events dilution would be high, and metals or other contaminants would be carried from the park down to the adjoining Avra Valley or Tucson Basin before significant infiltration could occur.

The 1994 boundary expansion of TMD encompassed the Old Yuma Mine Area, which includes a valid lode claim, a valid placer claim, and a disputed lode claim. Management of these claims transferred from BLM to NPS when the 1994 expansion bill was approved. Patent is being sought on the valid lode claim, and the claimant has submitted a plan of operations for the disputed lode claim. An approved plan of operations must be in place before any activity can occur on either claim. The placer claim consists of a refuse pile and two catchment basins which were built to process the refuse with cyanide leaching. There has been no indication to date that the claimant intends to pursue the placer claim.

Recommendation:
The tailings piles should be allowed to revegetate and stabilize through natural processes. Restoration efforts at these sites could cause more damage than they alleviate, especially if they required the use of heavy machinery. Transportation of machinery and concomitant road rehabilitation would damage vegetation directly and expose soil to subsequent erosion. Because there are no recognized threats to aquatic resources, rehabilitation would also be very difficult to justify from a cost/benefit perspective. Restoration efforts, if employed, should focus on encouraging natural succession processes. Lime treatment should be investigated as a means to neutralize acidity in the soil and runoff waters, and to provide a more favorable environment for plant recruitment.

EROSION OF ROADS AND TRAILS

There are eleven miles of unpaved roads in SAGU, and Tucson Mountain District contains the majority of these. The roads have been bulldozed into the desert and are not constructed to insure proper drainage; therefore, the surfaces degrade with the slightest precipitation. In addition, these roads are frequently located in or across major drainages. Although drainages are dry most of the year, even minor flows create washouts (National Park Service, 1995).

Given the climate and sparse vegetation in the desert, trails are also subject to erosion and can be significant sources of sediment. Soil compaction and other factors cause trails to become recessed below the elevation of the desert floor. Once this occurs the trail can intercept and concentrate surface runoff, becoming a channelizing conduit which effectively extends the drainage network of the watershed in which it is contained. In other words, the road or trail serves as an ephemeral stream bed. If trail and road density becomes significant, this can change storm runoff characteristics in favor of increased surface runoff, decreased infiltration, higher peak flows, increased sediment transport, and erosion of receiving stream channels.

Recommendation:
From a water resource perspective, erosion of roads and trails in TMD is causing little impact to the park's natural resources because water sources are limited to small springs and man-made water holes, and water-related or riparian resources are relatively nonexistent. Impacts are manifested in the form of damage to the park's roads and trails themselves, necessitating maintenance after each significant rainstorm. Within RMD, riparian communities and surface water sources do exist, and these resources could be affected by erosion of trails and roads or runoff from paved surfaces. Roads and trails should be constructed in such a manner that minimizes the factors that cause erosion. Important considerations include: crossing streams and washes at the elevation of the stream bed; constructing roads and trails with a positive slope and maintaining the surface near the elevation of the surrounding terrain; wing ditching as much as possible and draining to low slope areas (not necessary if positive slope techniques are employed); and, keeping grades to a minimum.

GROUND WATER CONTAMINATION

Ground water contamination has minimal potential to impact SAGU's natural resources because all water (surface and ground) flows from the districts to the surrounding areas. The one exception is in the Rincon Creek valley. The lower reach of Rincon Creek flows through sparsely developed private housing areas before entering the NPS expansion area. However, because this reach of Rincon Creek is ephemeral, there is little chance for water contamination to impact biotic communities. The major resource value lies within the habitat structure of the adjoining riparian corridor, and this resource is more threatened from a water quantity perspective than from a water quality perspective.

Because water in both districts is supplied by NPS-operated ground water wells, contaminated ground water in the Tucson Basin or Avra Valley could have implications from a visitor safety and public health viewpoint. Currently, there are no water quality concerns associated with these wells (National Park Service, 1995). This primarily results from the fact that ground water is moving away from the districts toward the center of the basin, and that the majority of the ground water recharge comes from losses to stream channels and via fractures in the mountain front. These streams and fracture systems drain undeveloped watersheds protected by the park.

<u>Recommendation</u>:
Continue monitoring public water supply wells in compliance with state and federal regulations.

CHECK DAMS, WINDMILLS, AND WATERING PONDS

One of the earliest projects completed by the Civilian Conservation Corps (CCC) in the Tucson Mountains was the construction of twenty-six check dams (Hall, 1990). The check dams and associated structures are on the List of Classified Structures and have been determined to be eligible for the National Register of Historic Places. Both earth fill and masonry construction techniques were used with the intention of reducing gully erosion and providing water sources for wildlife. Cisterns were sometimes integrated with the masonry dams to store water during dry periods. Water from the cisterns was pumped by windmill power to storage tanks and then gravity fed to shallow concrete watering ponds. The reservoirs behind the check dams are currently filled with sediment.

Two windmill structures have been restored and are in operation. They serve to mitigate the loss of wildlife watering sources along Brawley Wash, which were isolated from TMD by the construction of the CAP canal (Figure 3). The Dobe House Well is registered with the Arizona Department of Water Resources and is 34 feet deep. The depth to water at the time of measurement was 14.5 feet. The watering pond associated with this site is 22.5 feet long and 9 feet wide. Float valves are mounted in the pond to prevent continuous running. The Red Hill Well is also registered with the Arizona Department of Water Resources. The well is 35.2 feet in depth and the depth to water was 4.2 feet at the time of measurement.

<u>Recommendation</u>:
Unless the check dams are determined worthy of saving as a result of their eligibility for the National Register of Historic Places, they should be allowed to fail over time. Because these dams are relatively small and filled in with sediment, their failure, even if sudden, should not be a catastrophic event. The hydrologic view of these structures was best summarized by Leopold (1994) who said: "The results [of building thousands of small check dams in western gullies] have been not only useless, but in some cases conducive to more erosion." He recommends bank stabilization by vegetation as the best treatment for gullies in valley alluvium. In the case of SAGU, the "check dams" are mainly in high gradient rocky canyons where channel instability is unlikely.

The wind mills are ancillary features to the check dams and are insignificant with regard to the overall hydrology of the area. However, they may be important ecologically, and their merit should be based on their contributions to wildlife management in the areas they serve. If studies of wildlife utilization indicate these additional water sources are necessary and beneficial to maintaining native wildlife populations, then the dams and cisterns should be maintained.

EXOTICS AND RARE OR ENDANGERED SPECIES

Exotic species were not reported to be a significant component of SAGU's spring, seep, or riparian communities (R. Turner, U.S. Geological Survey, Retired, pers. comm., 1996; National Park Service, 1995). The extremely isolated nature of the perennial water sources and the long period of time they have been protected within SAGU's boundary may be the reason invasion has not been documented. However, another reason exotic species have not been identified may be due to the lack of base-line studies. The same general statement can be repeated for rare or endangered species. Given the isolated nature of SAGU's perennial water sources and their well-protected status, combined with the wide range of vegetative assemblages at varying elevations, it is possible that rare species reside in perennial surface waters.

A more complicated relationship between exotic species and hydrology may relate to changes in fire regimes as a result of the introduction of non-native grasses. Hardy exotic grasses have encroached in some areas and apparently increased the frequency and intensity of fires (Hastings and Turner, 1962). This increases the likelihood of rain events occurring on scorched ground, potentially increasing surface runoff, sediment transport, and peak flooding.

Recommendation:
Appendix A contains a proposal to inventory water sources and riparian areas within SAGU. A significant component of this inventory process will focus on biological attributes, including plant and animal identifications to determine the presence of exotic, rare, or endangered species to the extent feasible. Follow-up studies in areas having the best aquatic habitat could further refine knowledge of resident biotic communities. As for non-native grasses and other terrestrial plants affecting the fire regime, this issue would be best addressed by fire ecologists.

AIR QUALITY/ATMOSPHERIC DEPOSITION

Both districts are Class 1 airsheds under the Clean Air Act as a result of their wilderness designation in 1976. In compliance with this designation, ambient air quality monitoring, visibility monitoring, and research to determine air quality effects on vegetation, have been conducted since 1982. Working with the NPS Air Quality Division, SAGU is developing specific air quality related values to be protected under the Clean Air Act amendments.

The principal source of air pollution in the Tucson Basin is motor vehicle emissions. Regional sources, including mining, smelters, coal-burning power plants, and rock crushing, also contribute to air quality degradation (National Park Service, 1995). Because SAGU's boundaries encompass the drainage basins of its water sources, pollution from upstream or upgradient activities is not a threat. Given this setting, atmospheric deposition of air-borne pollutants has the highest potential to contaminate park streams and springs, and impact their native aquatic ecosystems.

Monitoring of atmospheric deposition has not been conducted at SAGU, but has been ongoing since 1980 at two southern Arizona sites in cooperation with the National Atmospheric Deposition Program (NADP). These sites are Oliver Knoll, 82 miles northeast of SAGU, and Organ Pipe Cactus National Monument, 116 miles southwest. Figure 6 shows no obvious trend toward a degrading quality of atmospheric deposition at these sites, and indicates that, at least on a regional basis, atmospheric deposition has not deteriorated (National Atmospheric Deposition Program, 1996). However, this does not preclude the possibility that local sources within the Tucson area are contaminating atmospheric deposition within the park to the same degree they are impacting the ambient air quality.

Recommendation:
As a result of SAGU's designation as a Class I airshed, its proximity to Tucson, documented air quality degradation, and sensitivity to atmospheric contamination from external sources, SAGU should seek to monitor atmospheric deposition as a site within the National Atmospheric Deposition Program. SAGU should seek funding for this program from external partners such as the NPS Air Quality Division, City of Tucson, Pima County, Arizona Department of Natural Resources, U.S. Forest Service, Environmental Protection Agency, University of Arizona, and other agencies or groups with an interest in environmental quality. At minimum, the site should be operated long enough (ten years) to determine if a reasonable correlation exists between atmospheric deposition parameter concentrations and trends at SAGU and the sites at Oliver Knoll and Organ Pipe Cactus National Monument. If a correlation is established the site could be discontinued; otherwise, continued monitoring would be required.

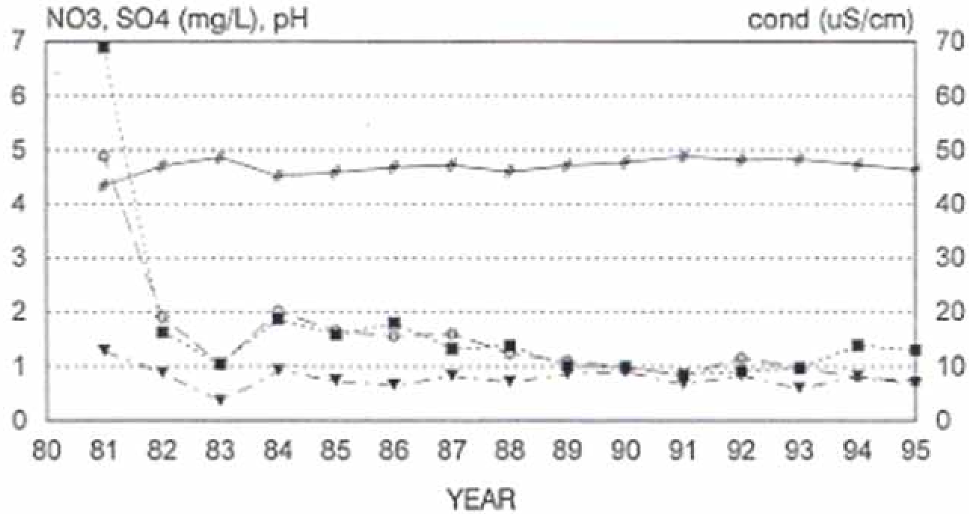
CONTAMINATION OF MANNING CAMP WATER SUPPLY

Manning Camp is a backcountry administrative site and campground located at 8,000 feet in RMD (Figure 2). Water serving the camp is supplied from a nearby ground water recharged pond. Human waste facilities at Manning Camp consist of pit toilets, and some visitors undoubtedly deposit their waste in nearby "cat holes." It is possible

FIGURE 6: Atmospheric deposition statistics from two air quality monitoring sites near Saguaro National Park

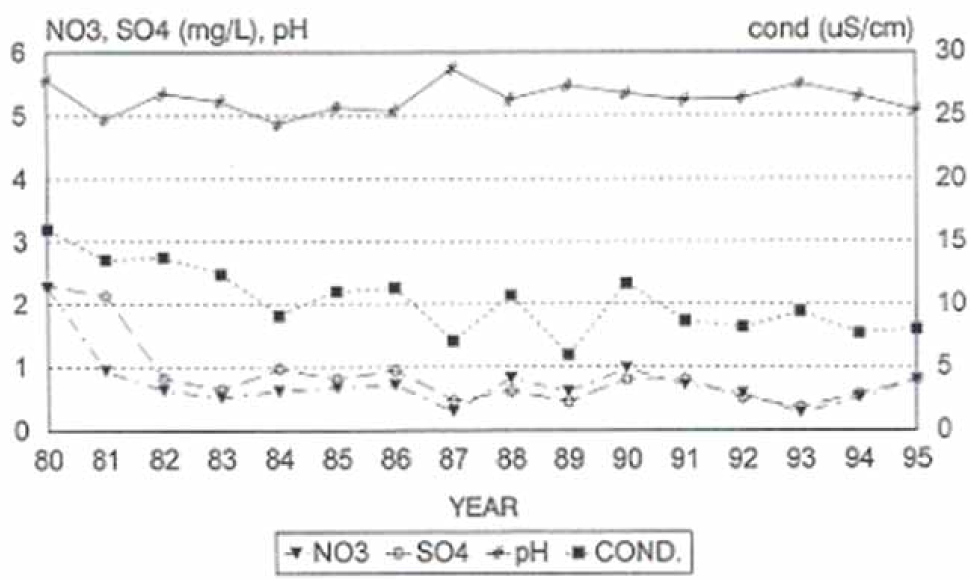
Oliver Knoll, Arizona

National Atmospheric Deposition Program, Annual Data Summary



Organ Pipe Cactus Nat'l Monument

National Atmospheric Deposition Program, Annual Data Summary



Values are yearly weighted mean except Cond. which is reported as median that leachate from the pit toilets and "cat holes" could contaminate the camp's only water source, especially during times of high fire activity when additional fire-related personnel are stationed at the camp.

Recommendation:
If possible, move pit toilets either outside or down gradient from the drainage area of the pond. Encourage NPS personnel to use the toilet facilities and deposit their waste outside or down gradient from the pond's drainage area, and educate visitors to do likewise. Continue to monitor the drinking water for the presence of fecal coliform bacteria and continue the present chlorination program.

STAFFING AND ONGOING PROGRAMS

The Division of Science and Resource Management has a staff of four permanent, base-funded positions. The Chief, Science and Resource Management (Meg Weesner) reports directly to the Superintendent and is responsible for natural and cultural resources. Each district has a Resource Management Specialist who oversees both natural and cultural resource programs. Wildlife Biologist Natasha Kline (RMD) and Vegetation Specialist Mark Holden (TMD) also use their professional expertise to direct programs in their functional areas. A Biological Technician (vacant) is assigned to TMD and assists with projects in RMD. Additional seasonal and term employees are occasionally funded through special projects.

As of 1996, the only on-going water resource project is public water supply monitoring of ground water wells which provide drinking water to both districts. The park tests water delivered to each district in compliance with applicable state and federal requirement. The park also operates a small water treatment facility at the spring which provides water for the backcountry cabin at Manning Camp. However, the park was funded for a water resources study commencing in FY97 which will inventory springs and other water sources and begin to identify and assess potential issues associated with local ground water withdrawals. The study plan for this work is currently being developed jointly by the park, the NPS Water Resources Division, and the University of Arizona.

Additionally, ground water and riparian issues near the NPS expansion area are being monitored through the activities of the Rincon Institute, a non-profit conservation organization dedicated to protecting the park's sensitive ecosystems in the Rincon Valley. The Rincon Institute (RI) was established in the late 1980s as part of a mitigation package for the proposed Rocking K Ranch resort and residential community. In 1992, RI personnel began monitoring the riparian ecosystem of Rincon Creek, which passes through both SAGU and the Rocking K Ranch. RI has established four permanent study sites along Rincon Creek to inventory vegetation, ground water, stream flow, and channel characteristics. Follow-up monitoring will be conducted every few years as finances allow. In addition, they are planning to monitor small mammals, reptiles, amphibians, and birds to establish correlations between habitat quality and wildlife productivity and diversity (Rincon Institute, 1995). With the programs and personnel available at the RI, they are well positioned to form beneficial partnerships with the NPS.

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Other contributors include Julio Betancourt and Don Pool with the U.S. Geological Survey; Bill Halverson, Ray Turner, and Tom Maddock with the University of Arizona; Ralph Marra with Tucson Water; and Dan McGlothlin and Bill Hansen with the NPS Water Resources Division.

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LITERATURE CITED

Anderson, S.R. 1988. Potential for Aquifer Compaction, Land Subsidence, and Earth Fissures in the Tucson Basin, Pima County, Arizona. U.S. Geologic Survey, Hydrologic Investigations Atlas HA-713. 3 sheets.

Anthony, R.G. 1972. Ecological Relationships Between Mule Deer and White Tailed Deer in Southeastern Arizona. Ph. D. dissertation, University of Arizona. Tucson, AZ. 123 pp.

Arnold, L.W. 1940. An Ecological Study of the Vertebrate Animals of the Mesquite Forest. M.S. thesis, University of Arizona. Tucson, AZ. 79 pp.

Bureau of Reclamation. 1986. Tucson Aqueduct, Phase B Modifications, Central Arizona Project. United States Department of Interior, Bureau of Reclamation, Lower Colorado Region. 79 pp

Burkham, D.E. 1970. Depletion of Stream Flow by Infiltration in the Main Channels of the Tucson Basin, Southeastern Arizona. U.S. Geological Survey Water Supply Paper 1939-B, U.S. Government Printing Office. Washington D.C.

Clemensen, A.B. 1987. Cattle, Copper, and Cactus: The History of Saguaro National Monument, Arizona. Historic Resource Study, National Park Service. Denver, CO. 271 pp.

Cordy, G.E. 1994. National Water Quality Assessment Program - Central Arizona Basins. U.S. Geological Survey, Fact Sheet 94-016. 2 pp.

Cuff, M.K., and S.R. Anderson. 1987. Ground water Conditions in Avra Valley, Pima and Pinal Counties, Arizona. U.S. Geological Survey Water Resources Investigation Report 87-4192. Tucson, AZ. 3 sheets.

Dotson, K., T. Garza, and C. Scott. 1990. Tucson Water Resources Plan, 1990 to 2100. Tucson Water. Tucson, AZ. 20 pp.

Gavin, T.A. 1973. An Ecological Survey of a Mesquite Bosque. M.S. thesis, University of Arizona. Tucson, AZ. 67 pp.

Groeneveld, D.P., and T.E. Griepentrog. 1985. Interdependence of Ground Water, Riparian Vegetation, and Streambank Stability, a Case Study. Pages 44 - 48 *in* Riparian Ecosystems and Their Management, Reconciling Conflicting Uses, First North American Riparian Conference. U.S. Forest Service. General Technical Report RM-120.

Hall, R.L. 1990. Final Report, Rehabilitation of Man-Made Water Sources to Mitigate Impacts of CAP Construction on Wildlife Resources. Tucson Mountain District, Saguaro National Monument. Tucson, AZ. 8 pp.

Halpenny, L. 1985. Evaluation of the Adequacy of Ground Water Supply, Ranchlands Water Company, Rincon Valley, Pima County, Arizona. Water Development Corporation. Tucson, AZ. 36 pp.

Hanson, R.T. 1989. Aquifer System Compaction, Tucson Basin and Avra Valley, Arizona. U.S. Geologic Survey, Water Resources Investigation Report 88-4172. Tucson, AZ. 69 pp.

Hanson, R.T., S.R. Anderson, and D.R. Pool. 1990. Simulation of Ground Water Flow and Potential Land Subsidence, Avra Valley, Arizona. U.S. Geological Survey, Water Resources Investigation Report 90-4178. 41 pp.

Hastings, J.R. 1959. Vegetation Change and Arroyo Cutting in Southeastern Arizona. Journal of Arizona Academy of Science, v.1, no.2. Pages 60-67.

Hastings, J.R., and R.M. Turner. 1962. The Changing Mile - An Ecological Assessment of Vegetation Change with Time in the Lower Mile of an Arid and Semi-arid Region. University of Arizona Press. Tucson, AZ. 317 pp.

Jemison, R.L. 1989. Conditions that Define a Riparian Zone in Southeastern Arizona. Ph.D. thesis, University of Arizona. Tucson, AZ. 252 pp.

Johnson, R.R., and L.T. Haight. 1985. Avian Use of Xeroriparian Ecosystems in the North American Warm Deserts. Pages 156 - 160 *in* R.R. Johnson et al. Technical Coordinators. Riparian Ecosystems and Their Management: Reconciling Conflicting Uses. U.S. Forest Service Technical Report RM-120. 523 pp

Johnson, R. R., and L.T. Haight. 1991. The Importance of Xeroriparian Ecosystems to the Wintering Avifauna of Saguaro National Monument. Pages 105 - 114 *in* Proceedings of the Symposium on Research at Saguaro National Monument. National Park Service. Tucson, AZ.

Judd, B.I., J.M. Laughlin, H.R. Guenther, and R. Handegarde. 1971. The Lethal Decline of Mesquite on the Casa Grande National Monument. Great Basin Naturalist, v. 31. pp. 153-159.

Kidwai, Z. U. 1957. The Relationship of Ground Water to Alluvium in the Tucson Area, Arizona. M.S. thesis, University of Arizona. Tucson, AZ. 69 pp.

Lacey, J.R., P.R. Ogden, and K.E. Forter. 1975. Southern Arizona Riparian Habitat: Spacial Distribution and Analysis. University of Arizona. Tucson, AZ, 148 pp.

Leake, S.A., and R.T. Hanson. 1987. Distribution and Movement of Trichloroethylene in Ground Water in the Tucson Area, Arizona. U.S. Geological Survey. Water Resources Investigation Report 86-4313. 40 pp.

Leopold, L.B. 1994. A View of the River. Harvard University Press. Cambridge, Massachusetts. 298 pp.

National Park Service. 1995. Statement for Management. Saguaro National Park. Tucson, AZ, 33 pp.

National Atmospheric Deposition Program. 1996. Annual and Seasonal Data Summaries, Oliver Knoll and Organ Pipe Cactus National Monument, Arizona. National Atmospheric Deposition/National Trends Network. Fort Collins, CO.

Osterkamp, W.R. 1973a. Ground Water Recharge in the Tucson Area, Arizona. U.S. Geological Survey. Reston, Virginia. Map I-844-E. 1 map

Osterkamp, W.R. 1973b. Map Showing Depth to Ground Water in Wells in the Tucson Area, Arizona, 1972. U.S. Geologic Survey. Miscellaneous Investigation Series, I-844-D. 1 map.

Osterkamp, W.R. 1974. Map Showing Ground Water Velocities in the Uppermost Saturated Alluvial Deposits of the Tucson Area, Arizona. U.S. Geological Survey. Miscellaneous Investigation Series, Map I-844-K. 1 map.

Osterkamp, W.R., and R.L. Laney. 1974. Map Showing Chemical Quality of Ground Water for Public Supply in the Tucson Area, Arizona. U.S. Geological Survey. Reston, Virginia, Map I-844-L. 1 map.

Rincon Institute. 1995. The Rincon Institute, 1991 - 1994 Profile. Rincon Institute. Tucson, Arizona. 14 pp.

Shand, J.D., and A.H. Underhill. 1985. Recreational Use by Visitors, Neighbors, and Organized Groups. Cooperative National Park Resources Studies Unit, University of Arizona. Tucson, AZ. 77 pp.

Smith, G.E.P. 1910. Ground Water Supply and Irrigation in the Rillito Valley. Agricultural Experiment Station, University of Arizona. Tucson, AZ. 242 pp.

Snyder, K.A. 1995. Patterns of Plant Species Diversity and Composition in a Semi-arid Riparian Ecosystem, University of Arizona, Tucson, AZ, 321 pp.

Streitz, R. 1962. Subsurface Stratigraphy and Hydrology of the Rillito Creek-Tanque Verde Wash Area, Tucson, Arizona. M.S. thesis, University of Arizona. Tucson, AZ. 60 pp. 1 sheet.

Upper Santa Cruz Basin Mines Task Force. 1979. Upper Santa Cruz Ground Water Quality Baseline Report. Pima Association of Governments, 208 Program. Tucson, AZ. 71 pp.

APPENDIX A

PROJECT NUMBER:SAGU-N-031.002

TITLE:INVENTORY WATER SOURCES AND RIPARIAN AREAS
FUNDING STATUS:FUNDED

PROBLEM STATEMENT

Saguaro National Park (SAGU) is located in south central Arizona near the northern limits of the Sonoran Desert. The park is visited by almost one million people each year who take part in hiking, plant study, animal observations, and general desert enjoyment (Shand and Underhill, 1985). The presidential proclamation establishing the park references the outstanding botanical features, namely the Saguaro and other cacti, along with the scientific interest of the area as the primary reasons for preservation. The east unit (Rincon Mountain District) was established in 1933 and now encompasses 67,293 acres. The west unit (Tucson Mountain District) was added to the monument in 1961, mainly to protect the area from mining developments, and now encompasses 24,034 acres. Boundary expansions occurred in 1976, 1991, and 1994. In 1976, 71,400 acres were designated as wilderness, and the area was redesignated as a national park in 1994. Elevations range from 2,200 to 8,666 feet. Six discrete vegetative assemblages are found along this vertical profile.

Water is a critical resource at Saguaro National Park. It provides an essential element of the area's biologic communities in the midst of a harsh, desert environment. Springs, seeps, perennial stream reaches, and riparian areas sustain unique habitats important in maintaining the desert ecosystems that the park was established to protect. Past land use activities, on-going ground water withdrawals, and continued growth in the Tucson Basin have created major changes in hydrologic processes and riparian landscapes within and adjacent to the park.

The Tucson area depends almost entirely on ground water to supply its municipal, agricultural, and industrial water needs. The rate of ground water withdrawal far exceeds aquifer recharge, resulting in ground water mining, which has been taking place for many years. The impacts of ground water withdrawal to the Tucson Basin's perennial streams and associated riparian corridors can only be described as devastating. Perennial streams no longer exist in the basin, and riparian corridors have been diminished in both quantity and quality.

The cities' growth and intensive development have expanded to the boundaries of both park units. Basic data describing and quantifying the park's water resources have never been collected; therefore, changes in plant and animal communities cannot be correlated with alterations of fundamental hydrologic factors responsible for the existence of these ground- and surface-water-influenced areas.

PROJECT DESCRIPTION

This proposal outlines a process for inventorying all surface water resources and ground water-dependent, riparian communities. The inventory will locate and characterize each water feature using standard hydrologic parameters. Measurements and descriptions will rank water sources and zones of ground water influence in terms of habitat importance and potential sensitivity to water table declines and other factors. Locations will be determined using GPS technology, data will be stored in computer and hardcopy files, and a GIS database will be constructed. This hydrologic information and analysis, used in conjunction with ongoing wildlife and vegetation studies, will provide the basic link between physical processes and biological systems needed to initiate management actions to protect Saguaro National Park's aquifers and the ground water resources that support its unique floral and faunal habitats.

The objectives of this project are to:

1. Identify all known springs, seeps, perennial stream reaches and riparian areas using topographic maps, reports from local residents, park visitors, and park staff, and color infrared aerial photography.

2. Complete a field inventory of these areas, using GPS technology to assign latitude and longitude coordinates to identified features and map the perimeters of discrete riparian areas.

3. Record information about each water resource feature, including the parameters shown in Table 1.

4. Store these data in computer format and hard-copy files for future reference.

5. Prepare a concise report tabulating the project data and highlighting accomplishments and insights gained during the field work.

6. Prepare GIS data layers showing various water features and selected attributes.

7. Share this information with WRD Water Rights staff currently involved in the adjudication process for SAGU to attain recognized priority dates for these water sources for the maintenance of natural flow.

Table 1--Water Resource Inventory Parameters

SPRINGS AND PERENNIAL STREAM REACHES	SEEPS	RIPARIAN AREAS
Discharge	Wetted Area	Areal extent of riparian vegetation
Conductivity & temperature	Areal extent of riparian veg.	Nature of riparian veg.
Geologic setting	Nature of riparian veg.	Thickness of alluvium
Length of surface stream	Presence of bedrock pools	Depth to ground water
Wetted area	Thickness of alluvium	Dead or dying vegetation
Areal extent of riparian veg.	Depth to ground water	Presence of stumps
Nature of riparian veg.	Aquatic biota	Stream channel transects
Thickness of alluvium	Developments	
Aquatic biota		
Developments		

Field work and inventory parameters will be further defined through consultation with representatives from the NPS Water Resources Division, U.S. Geological Survey, and the University of Arizona Department of Hydrology and Water Resources. All data will be recorded in computer format and in hard copy files. Spring and seep data will also be stored in a USGS database already established for this purpose.

Inventory work will be conducted between March and June of each year, during the driest season. Photographs will be taken to provide the best view of the inventory area and step log techniques will be used to facilitate repeat photography. Two individuals with targeted skills will be recruited to work together on this field project for safety considerations. One employee will be knowledgeable in the biology of the area and the other in hydrology/geology.

BUDGET

Item	**Year 1**	**Year 2**
Hydrologic Tech (GS5, 4 mo/yr)	$ 7,000	$ 7,000
Biol. Science Tech (GS5, 4 mo/yr)	7,000	7,000
GSA Vehicle (4-wheel-drive pickup)	2,000	2,000
GPU Equipment (Trimble GeoExplorer)	3,400	-0-
Equipment and Supplies (auger, compass, maps, cond/temp meter, pH meter, film, etc.)	1,000	600
Color Infrared Photography (1:12000 scale covering 91,000 acres)	8,000	-0-
Annual Totals	**$ 28,400**	**$ 16,600**
Grand Total		**$ 45,000**

With this proposal, *SAGU is requesting $28,400 in FY97 and $16,600 in FY98* to be supplied through the Other Water-Related Issues category of the WRD project funding mechanism.

APPENDIX B

Technical Assistance Request - Assess Impacts of Ground Water Declines
Saguaro National Park

Overdraft pumping to supply municipal, industrial, and agricultural needs has resulted in ground water declines in the Tucson Basin and Avra Valley (Figure 1). Water table declines have the potential to affect Saguaro National Park's (SAGU) resources through:

1. loss of phreatophytic vegetation;

2. decreased capacity of water supply wells;

3. aquifer compaction and land subsidence; and,

4. fracture dewatering of bedrock with resulting loss of recharge to springs and seeps.

Technical assistance is required to investigate these issues in more detail, quantify problems where possible, and make recommendations which define the necessary level of response.

1. <u>Loss of phreatophytic vegetation:</u>
Water level declines in riparian areas can dramatically affect the nature and quality of the habitat provided by phreatophytic vegetation. With the continued loss of riparian habitat in the Tucson Basin, preservation of riparian habitat within the park becomes increasingly critical. Too little is known about the interactions between ongoing ground water withdrawals, future developments, and the physical hydrology and biological processes active within the park's riparian areas. A successful preservation scheme must include some means of quantifying and offsetting potential water level declines if these declines are determined to threaten riparian resources.

Three riparian areas within the eastern Rincon Mountain District (RMD) are situated in areas susceptible to water level declines. The western Tucson Mountain District (TMD), because of its smaller catchment basins, minor orographic rainfall, and differing geology, does not contain any areas mapped with riparian vegetation. The riparian areas of concern within RMD are shown in Figure 2, and include Rincon Creek within the park expansion area, lower Box Canyon, and the lower reaches of the drainages feeding Tanque Verde Wash. Riparian habitat is also present at higher elevations along mountain drainages, but these areas are not considered readily susceptible to water table declines. With the expansion of Tucson, and proposals for major developments near these three areas, new well fields could lower water tables, resulting in the loss of phreatophytes and their associated value to the park's wildlife.

The ground water reservoirs supporting the riparian areas within RMD are not directly connected to the Tucson Basin aquifer. As shown in Figure 5, the major aquifer of the Tucson Basin lies outside the boundaries of RMD. This is important because the drawdown within the Tucson Basin is, in most areas, already sufficient to place the water table beyond the depth where phreatophytic vegetation can access and utilize this resource. Osterkamp (1973b) reported depth to water in wells in the Tanque Verde Wash and Rincon Creek areas is often less than 30 feet, and this is supported by the riparian vegetation mapped in these areas. The thickness of the saturated alluvium in the three areas varies greatly, but the overall storage capacity is orders of magnitude less than the saturated sediments within the Tucson Basin, and well field development could have an immediate and pronounced effect on drawdown.

Burkham (1970) determined that within Tanque Verde Wash and Rincon Creek, the thickness of the saturated alluvium varies from twenty to over one hundred feet thick. The depth to ground water below Tanque Verde Wash was five to thirty feet, and from ten to one hundred feet under Rincon Creek's channel. He noted that, in general, alluvial thicknesses and ground water depths are least near the mountains. Seepage measurements performed by Burkham (1970) revealed relatively low infiltration rates along Rincon Creek within the park expansion area, indicating small thicknesses of permeable alluvium and interferences with shallow ground water. In lower reaches of

Rincon Creek, infiltration rates were extremely high as a result of increased thickness of alluvial sediments and the spreading out of the flow over a broader channel and flood plain.

In Halpenny's (1985) evaluation of twelve wells in lower Rincon Valley, he determined that there has been no consistent drawdown of water levels through time, and concluded the Pantano Fault (shown in Figure 5) prevents water level declines in the Tucson Basin from affecting the levels in the Rincon Valley. Halpenny noted water levels within wells along the lower reaches of Rincon Creek fluctuated with wet and dry periods. Any monitoring well strategy proposed for Rincon Valley should be in place long enough to demonstrate the magnitude of the inherent seasonal flux before trends could be superimposed on future water levels.

Ray Turner (U.S. Geological Survey, Retired, pers. comm., 1996) described recent developments along Tanque Verde Wash where drawdown has apparently affected the riparian community therein. Tucson Water located municipal wells outside the Tucson Basin and within the saturated alluvium that lies between the Rincon Mountains and the Tucson Basin along Tanque Verde Wash. When the wells were activated, cottonwood trees began to die, and public concern caused the city to halt pumping. Because of the continued growth in Tucson, and the moratorium on the use of CAP allocations, Tucson Water is again expanding its well field into the Tanque Verde area.

To the south of RMD, another water development project, the Rocking K Ranch, is proposed for lower Rincon Creek. Developers anticipate having 9,000 residents within the Rocking K, and have been granted a permit by the Arizona Department of Water Resources to withdraw 4,400 acre feet/year (3,927,788 gal/day) from the underlying alluvial aquifer (Halpenny, 1985). There is clear potential for this magnitude of extraction to impact park resources in the Rincon Creek and Box Canyon areas through depletion of ground water reserves and subsequent declines in riparian water tables.

Recommendation:
To address the issues connected to declining water tables, technical assistance is requested from a ground water hydrologist with the Water Resources Division. The individual should be familiar with the interactions between water tables, well field development, and phreatophytic vegetation in a western landscape. Specific actions recommended include:

•Amount and quality of phreatophytic vegetation within the riparian zones shown in Figure 2 and their relative dependence on ground water.

•Hydrologic connectivity between areas of potential development and low elevation riparian areas.

•Development of a working model of ground water behavior and estimate the potential for water table declines to extend into the park.

•Background investigations to locate and interpret water level data available in the area which could help quantify present ground water conditions and seasonal fluctuations of water tables.

•Map relationships (where data exists) between water levels, alluvium, and phreatophytic vegetation (i.e., what depth to ground water supports riparian vegetation and how thick does the saturated alluvium have to be to support a perennial aquifer).

•Recommendations as to whether or not a ground water monitoring scheme should be developed to monitor potential problem areas, and, if necessary, how the monitoring strategy should proceed. If a monitoring program is recommended, assist SAGU in funding and implementing the monitoring scheme.

•Guidance to NPS managers involved in purchasing lands within the park expansion area concerning the appropriate water rights investigations and purchases needed to protect ground water and riparian resources.

2. Decreased Capacity of Water Supply Wells:

Deep wells provide water for both districts. RMD draws over one million gallons annually from a 500 foot deep well located on government property one mile to the west of the boundary. As inferred from Figure 3, the production well lies outside park boundaries because SAGU does not overlie the Tucson Basin aquifer anywhere within its boundary. A 560-foot deep well within TMD provides 700,000 gallons per year from the saturated alluvial deposits within the Avra Valley. This well is located in the extreme southwest corner of TMD and taps the Avra Valley aquifer. The water is not treated at either unit but passes all state tests for public drinking water sources (NPS, 1995).

At present, SAGU management is negotiating with Tucson Water to connect RMD with the city's distribution system, and would no longer have a direct need for the wells in the Tucson Basin. This would alleviate any potential concern over decreased capacity affecting RMD. A map of measured water level declines in Avra Valley from 1940 to 1978 shows about 110 feet of drawdown at TMD's southwest boundary near the location of the water supply well. Using simulation modeling, the same area is predicted to undergo between 200 and 250 feet of water level decline by the year 2025, as compared to the 1940 level (Hanson et. al., 1990).

Recommendation:
Technical assistance is also required to conduct a review of any water level records available for the TMD well. This review is intended to insure an abundant supply of ground water is available to serve this district, and to forecast any potential problems. In addition, a determination should be made as to whether or not TMD should be monitoring the water level of its supply well, and if so, how should they proceed with this monitoring.

3. Aquifer Compaction and Land Subsidence:
According to Cordy (1994) major land subsidence has already occurred in the Phoenix area where water level declines have been in excess of 500 feet. Aquifer compaction has the potential to damage park infrastructure such as water, sewage, and other distribution lines, roads, and buildings. However, the units are, for the most part, not situated over the alluvial basins where settling would occur. In fact, RMD does not overlie the Tucson Basin alluvial aquifer at any location (Figure 5). The only areas with a potential for subsidence are the extreme eastern and western portions of TMD.

Recommendation:
Hanson (1989) shows land subsidence of 0.5 feet has already occurred in the Tucson Basin, and 1.1 feet in Avra Valley. Maps of potential maximum land subsidence show no significant subsidence near the boundaries of TMD or its well. It appears drawdowns in excess of 250 feet initiate the compaction process, which can then occur rapidly after reaching this threshold level (10 feet of compaction can be expected with 350 feet of drawdown). Compaction occurs when water level declines cause vertical pressures to exceed the preconsolidated-stress threshold of the alluvial deposits. Because large amounts of drawdown are required to initiate compaction, it is recommended that no action be taken regarding this issue until water level declines begin to approach the 250 feet threshold. Technical assistance is required to review well level data, and water level declines near TMD, and determine if the recommendation stated above is adequate to address this issue.

4. Fracture dewatering of springs and seeps:
Part of the Tucson Basin and Avra Valley's recharge arrives via fracture transport from the mountain front as described by Osterkamp (1973a) in the caption of Figure 4. Therefore, fracture water and basin water are hydraulically connected to some degree. Drawdown of water levels in the Tucson Basin, and the smaller aquifers in Tanque Verde Wash and Rincon Creek Valley, could result in decreased back pressure on mountain fracture systems and the loss of springs or seeps dependent on a fully saturated fracture to provide surface flow. The hydraulic behavior of fracture connectivity is speculative, and is more a hypothesis than a working model.

Recommendation:
The prescribed course of action is to inventory these mountain water sources. A proposal for this is currently awaiting funding from the Water Resources Division. An inventory, with return trips and repeat measurements, would allow SAGU managers to be aware of changing water conditions. If a loss of water sources or related attributes is noted, efforts could then be undertaken to determine if a linkage could be made between basin water level declines and fracture dewatering. If a linkage could be shown, SAGU may be able to use its adjudication to

take some form of protective action. Technical assistance is required to review this recommendation and make a determination on its adequacy.

For more detailed information regarding water resources issues at SAGU, please contact Mark Flora, Chief, Planning and Evaluation Branch, Water Resources Division and request a copy of *Water Resources Scoping Report, Saguaro National Park* or contact Meg Weesner, Chief, Science and Resource Management, Saguaro National Park.

As the nation's principal conservation agency, the Department of the Interior has the responsibility for most of our nationally owned public lands and natural and cultural resources. This includes fostering wise use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for enjoyment of life through outdoor recreation. The Department assesses our energy an*d* mineral resources an*d* works to ensure that their development is in the best interests of all our people. The Department also promotes the goals of the Take Pride in America campaign by encouraging stewardship and citizen responsibility for the public lands and promoting citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.